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FIELD TESTS WITH COMPOSTS INCORPORATING HUMAN FAECES

STUDIES ON THE CONTROL OF FAECAL-BORNE DISEASES IN NORTH CHINA, NO. XIX

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THE first paper in this series [1] appeared in the *Chinese Medical Journal* in February 1937 and described the public-health problems that have arisen in North China through the use of human faeces as a fertilizer. Methods of attacking these problems were also suggested in that paper. A series of papers reporting results of studies of the public-health problems involved has already been published [2–8, 11–16], and two papers dealing with the chemistry of Chinese native types of fertilizer employing human faeces have also appeared [9, 10]. A summary of the effectiveness of methods of composting for disposing of human faeces in a sanitary way was published in a mimeographed report [17], and a general description of the whole composting project was published in the *Asiatic Review* [18].

These studies have shown that by composting human faeces with animal manures and straw or other vegetable matter it is possible to conserve about 80 per cent. of the nitrogen, whereas native methods of composting with earth are insanitary and nitrogen losses generally exceed 50 per cent. Two main types of compost were produced, one utilizing human faeces together with horse- and cow-manure and straw, and the other made with human faeces and the vegetable-matter fraction of city street-waste or garbage. It was decided to test these types of compost in the field by comparison with native fertilizers, faeces cake, and pig-pen manure, and with the inorganic fertilizers, ammonium sulphate, calcium phosphate, and potassium sulphate. The present paper is a report of the results of these studies until they were brought to a premature end by the Japanese occupation at the end of 1941. This paper also reports a study of the moisture and nitrate in the field plots.

Preliminary experiment.—This was carried out with the helpful co-operation of the Chinese Central Agricultural Research Bureau at an experimental farm on the outskirts of the city of Tsinan, capital of Shantung Province, North China. It was in the form of a 5×5 Latin square. The five treatments were: (1) faeces and straw compost (hereafter called farm compost), (2) pig-pen manure, (3) faeces cake, (4) ammonium sulphate, and (5) blank. The farm compost was made of human faeces and wheat-straw with a small amount of horse- and cow-manure and soil added. Pig-pen manure is the native fertilizer produced by adding human faeces and urine together with soil and all farm wastes to a pit in which pigs are kept. It is a kind of soil compost. Faeces cake is made by drying human faeces into thin cakes; it is commonly made around North China cities. The four different fertilizers were all used

at the same nitrogen level, which was equivalent to the normal amount used by Chinese farmers in that part of Shantung (about 54 lb. N per acre per crop). This experiment was designed not only to test the relative availability of the different nitrogen carriers but also their residual effects. To do this each plot was split into three sub-plots. When the second crop was put in only two of the sub-plots were fertilized. When the third crop was put in only one of the sub-plots was fertilized, and when the fourth and fifth crops were put in no fertilizers were applied. It was thus possible to see the residual effects of one, two, and three successive applications on several succeeding crops. The crops used were winter wheat and late millet. The latter was planted just after the wheat had been harvested. Thus two crops were taken from the land each year. Beginning with millet planted in the summer of 1936 the continuous

TABLE 1. *Preliminary Experiment. Yields in Pounds per Acre*

Crop	*Blank*	*Pig-pen manure*	*Farm compost*	*Faeces cake*	*Ammonium sulphate*	*Mean of fertilized plots*
Millet 1936 *a, b, c* (all fertilized)	1,644	1,680	1,709	1,848	1,846	1,771
Wheat 1936–7 *a, b*	1,254	1,540	1,500	1,899	1,862	1,700
(*a* and *b* fertilized) *c*	1,254	1,283	1,377	1,404	1,566	..
Millet 1937 *a*	1,044	1,320	1,535	1,776	1,838	1,617
(*a* fertilized) *b*	1,044	1,142	1,187	1,213	1,677	..
c	1,044	1,044	1,142	964	1,008	..
Wheat 1937–8 *a*	743	959	933	912	1,383	1,047*
(no fertilizer) *b*	743	833	862	1,005	900	..
c	743	776	789	748	841	..
Millet 1938 *a*	1,783	2,102	2,088	1,911	2,005	2,027*
(no fertilizer) *b*	1,783	1,965	1,985	1,809	1,757	..
c	1,783	1,816	1,892	1,730	1,744	..

* Mean of plots with three previous fertilizations.

succession was millet–wheat–millet–wheat–millet, the final harvest being in autumn 1938. Table 1 gives the yields for the whole experiment. Seasonal variations show up in the fact that the unfertilized 1938 millet crop has a greater yield than the mean fertilized 1936 millet crop. The much lower yields of wheat in the 1937–8 crop than in the 1936–7 crop can only be partly ascribed to fertilizer effects. The general conclusions that can be drawn from this experiment are:

1. Faeces cake and ammonium sulphate are readily available nitrogen carriers. Pig-pen manure and farm compost are slowly available nitrogen carriers.
2. Faeces cake and ammonium sulphate produce immediate responses, whereas significant responses may not be given by pig-pen manure and farm compost until after several successive applications of fertilizer have been made. Throughout the experiment the blank plots were successively cropped without any addition of fertilizer.
3. The residual effect of ammonium sulphate is significant but is short-lived.

4. After two or three fertilizer applications, pig-pen manure, farm compost, and faeces cake appear to have residual effects on the following crop, but the differences are not large enough to be judged significant. The unusually high standard of error may be partly responsible for this.
5. Pig-pen manure, farm compost, and ammonium sulphate produce significant residual effects on the second following crop after three successive fertilizings. The residual effect of ammonium sulphate is the smallest.
6. The residual effects of pig-pen manure and farm compost appear only after several years of successive applications.
7. In a good year with annual application of around 100 lb. N per acre and double cropping, fertilized land averaged 28·3 bushels per acre of wheat, compared with 21 bu. for untreated land. In a poorer year the residual effect of the previous year's treatment still gave better yields; thus 17·5 bu. per acre of wheat on previously fertilized land compared with 12·4 bu. on unfertilized land.
8. In a good year, faeces cake and ammonium sulphate appeared to give 50 per cent. greater yield than unfertilized soil.

Experiment A.—Political conditions after 1938 made the carrying out of field tests in the rural areas very difficult and, since suitable land for experiments within Cheeloo University campus was too limited, it was decided to set up a series of metre-square stone-kerbed plots, somewhat like a magnified pot experiment. A small field was excavated to a depth of 18 in. with the exception of 100 metre-square blocks of soil in 5 rows of 20 which had only the top 10 in. removed. Limestone kerbs were fitted around these subsoil blocks up to the former ground-level, and finally a homogenized topsoil was filled in to the top 10 in. of each plot. The space between plots was then filled in. This gave 100 plots each of 1 sq. m., and it was possible to plant these and the spaces between at an even rate, thus giving a solidly planted field and eliminating edge-effects. Two experiments were run in this field. The first one (Experiment A) used 4 rows of 20 plots. These were divided into 10 blocks and within each block the following treatments were randomized: (1) farm compost, (2) city compost, (3) pig-pen manure, (4) faeces cake, (5) ammonium sulphate, (6) monocalcium phosphate, (7) potassium sulphate, (8) blank. Farm compost was composed mainly of straw and human faeces with some cow- and horse-manure added. City compost was composed of the organic fraction of city street-waste (garbage) screened out and composted with about 20 per cent. of human faeces. The nitrogen-carrying fertilizers were all put on at the same rate, approximately 54 lb. N per acre, P_2O_5 at the rate of 67 lb. and K_2O at the rate of 54 lb. per acre. The crop rotation followed is one which is common in that part of North China, viz. winter wheat, soya beans, fallow, millet, after which it is repeated. Fertilizers are applied only to the wheat and millet crops. With winter wheat, organic fertilizers were applied in the autumn immediately before sowing, whilst 'inorganics' were applied in early spring. With millet, all fertilizers were applied at the time of sowing. A preliminary crop without

fertilizers was taken and showed a satisfactorily low standard of error. The first crop of this experiment was winter wheat, sown in autumn 1939. This was harvested at the end of May 1940 and soya beans were planted a month later, being harvested early in October. Thereafter the land was left fallow till April 25, 1941, when millet was sown. It was harvested early in September and a month later winter wheat was sown. Two months later Japanese troops occupied the university and all work had to be suspended. The wheat that had been sown could not be properly looked after, but in the spring it was possible to apply the inorganic fertilizers and permission was obtained in May to reap the crop. Sparrows had eaten most of the grain and only the straw-weight could be obtained. Even this was very poor owing to an unusually dry spring. When the soya beans were planted in 1940 it was decided to see to what extent moisture was a limiting factor in crop yields, and for that crop every second block was irrigated. It was not necessary to irrigate the millet crop the following summer as rainfall was adequate, and it was impossible to irrigate the next wheat crop owing to the Japanese occupation.

TABLE 2. *Experiment A. Yields in Pounds per Acre*

Crop	*Farm compost*	*City compost*	*Pig-pen manure*	*Faeces cake*	*Ammon. sulph.*	*Calc. phosph.*	*Potass. sulph.*	*Blank*	*Mean*
Wheat 1939–40 (grain) . .	982	1,222	1,063	1,243	1,517	1,126	1,150	1,050	1,169
Soya beans, 1940 (grain):									
irrigated . .	308	295	315	383	315	302	329	342	322
not irrigated .	134	161	87	128	94	154	147	128	129
Millet 1941 (grain).	2,418	2,967	2,581	2,986	3,023	2,650	2,485	2,447	2,695
Wheat 1941–2 (straw only) .	803	1,060	835	963	997	974	818	850	912

General conclusions from Experiment A.—1. Farm compost, pig-pen manure, and potassium sulphate appear to be no better than blank at the rates supplied.

2. Calcium phosphate appears to be a little better than farm compost, pig-pen manure, potassium sulphate, and blank.

3. City compost, faeces cake, and ammonium sulphate appear to be much better than farm compost, pig-pen manure, potassium sulphate, and blank.

4. Responses to faeces cake and ammonium sulphate confirm the conclusion of the previous experiment that they are rapid-acting nitrogen carriers; and city compost seems to be the same.

5. The absence of response from potassium sulphate seems to indicate that in the absence of nitrogen and phosphate it is not a limiting factor.

6. Yields of soya beans under irrigation show that the absence of moisture is a limiting factor during the drier part of the year. Study of the following millet crop showed that soya beans under irrigation depleted the soil nutrient reserves more heavily than where unirrigated.

This showed clearly, although there was a 7 months' fallow between soya bean harvest and planting of millet. Faeces cake and ammonium sulphate gave significantly higher responses than farm compost on plots previously depleted.

Experiment B. Effect of different nitrogen levels using farm compost.—In the late spring of 1941 another experiment was begun on the remaining unused row of 20 stone-kerbed plots. These were divided into 5 blocks with 4 treatments randomized in each. During the previous summer soya beans had been grown in these plots. In one plot of each block the beans had been cut and turned in while green in order to study their nitrification. This study will be reported below. The plots were fallowed during the following winter. In early May, millet was sown. The treatments used in this experiment were multiples of the amount of farm compost used in Experiment A, viz. (1) double farm compost (107 lb. N per acre); (2) four-times farm compost (214 lb. N per acre); (3) eight-times farm compost (428 lb. N per acre); and (4) blank. The millet crop was followed by a winter wheat crop which was also treated at the same rate. As in the previous experiment, owing to the Japanese occupation and restrictions, it was possible to get only the straw of this latter crop. The crop yields are shown in Table 3. With the millet crop four-times farm compost and eight-times farm compost were significantly better than blank. With the wheat (straw) crop, all farm-compost treatments were significantly better than blank despite the fact that yields were all extremely low owing to the unusually dry season.

TABLE 3. *Experiment B. Yields in Pounds per Acre and Grain/Straw Ratio*

Crop	*No compost*	*Twice farm compost*	*Four-times farm compost*	*Eight-times farm compost*
Millet 1941 (grain) .	1,431	1,829	2,127	2,266
Wheat 1941–2 (straw only) . . .	357	591	691	817
Millet 1941 (grain/straw ratio) . .	4·0	3·11	3·09	2·76

Quantities of nutrients removed in crops.—Only two crops were analysed to find the amount of nutrients (N, P, K) that were removed. The first one was the preliminary millet crop on the small stone-kerbed plots. It received no fertilizer and the yields were only fair. The second was the wheat crop (Expt. A) which followed it and was treated at the rate mentioned above. Table 4 gives the quantities of N, P, and K removed in lb. per acre for both grain and straw. It will be noted that grain removes more nitrogen than phosphorus and much more nitrogen than potassium, but with straw, much more potassium is removed than nitrogen, and the phosphorus removed is even less. Millet removes much more nutrients from the soil than wheat because it is a much heavier cropper. Wheat removed much less nutrients from the soil than were

TABLE 4. *Quantities of N, P, K removed in Crops (Pounds per Acre)*

	N	P_2O_5	K_2O
Millet 1939, without fertilizers:			
Grain	43·69	23·95	11·57
Straw and chaff	45·89	23·08	78·94
Total	89·58	47·03	90·51
Wheat 1939–40, with fertilizers:			
Grain	15·73	9·57	3·28
Straw	4·68	3·55	17·60
Total	20·41	13·12	20·88

added in the fertilizer, whilst millet removed much more. If the crops had been better much greater quantities would have been removed. Thus we see that at the rates at which we added fertilizer, the amount of phosphorus was adequate or possibly high, but the amounts of nitrogen and potassium were inadequate. The inadequacy of supply of potassium in the fertilizers is not so serious as the soil is well supplied with that constituent, but the amount of nitrogen supplied was definitely limiting as shown by Experiment B. More experiments are required to elucidate this problem further.

Moisture and Nitrate Changes in Stone-kerbed Plots

The moisture and nitrate changes in the stone-kerbed plots were studied at the same time as the crop tests. Samples were taken with an auger of diameter 1 in. A small metal tray was made with a hole in the centre underneath which was soldered a short brass tube nearly 2 in. long and just wide enough to allow the auger to pass. When the tray was laid on the ground the tube pressed into the loose surface-soil, and it was thus easy to take a sample to the required depth without any surface-soil falling into the hole and contaminating the sample. Several samples were taken in each plot, mixed, and put into tightly stoppered boiling-tubes which were afterwards weighed before being put in racks in the drying-oven and dried at 105° C. After drying, samples were taken for the determination of nitrate, which was made by the phenoldisulphonic-acid method until the effect of human faeces in some of the treatments began to be troublesome. Thereafter nitrate was determined by a reduction method.

The study of moisture and nitrate was divided into two sections: (1) plots 1–80 of Experiment A, and (2) plots 81–100 of Experiment B.

Experiment A. Plots 1–80.—Figures for moisture were all very close, so an average for all the plots gives a good picture of moisture conditions. They correlate well with rainfall and irrigation except where a crop in full growth was using up moisture very rapidly. Moisture was lost very slowly under winter-fallow. Graphs were drawn for the nitrate-content of individual plots and grouped according to treatments. These showed that in spite of some variability due to sampling it was possible to average them into single graphs. These average graphs for the eight

different treatments were graphed together and showed remarkable closeness. There are three obvious peaks: (*a*) July 24, 1940, with hot moist weather and soya beans just beginning to grow; (*b*) Nov. 13, 1940, cool dry weather but just 1 month after the soya bean harvest; reflecting nitrification of soya bean roots left in the soil; (*c*) the most pronounced peak is in very warm dry weather at the end of May 1941, about a month

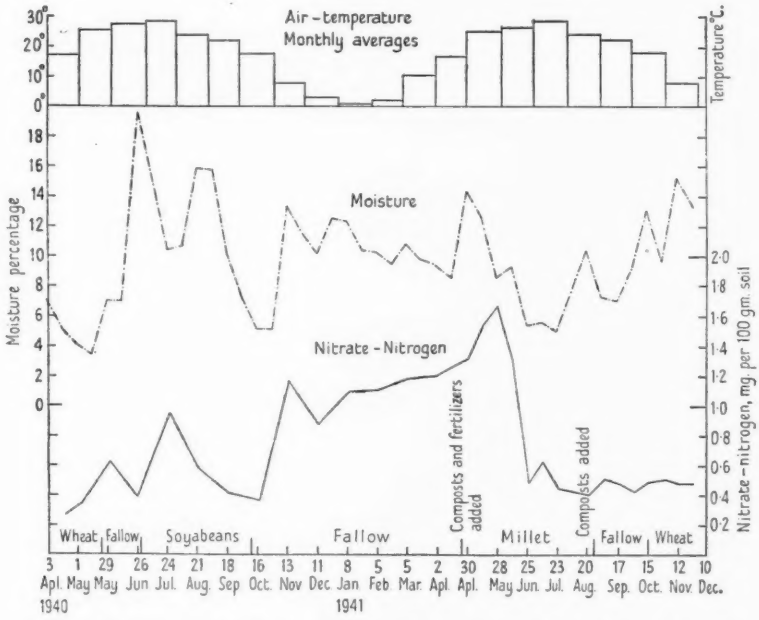

FIG. 1. Experiment A: Plots 1–80. Results of moisture and nitrate–nitrogen determinations.

after fertilizers and composts had been added and a millet crop was just beginning to shoot. As the millet developed there was a very rapid drop in the nitrate percentage in the soil. At the third peak, city compost and faeces cake showed much more nitrate formation than the others, but it is doubtful if the amount is significantly larger than the others although these points are an average of 4 and 5 plots respectively and cannot be due to sampling variation. This confirms what was borne out by the crop tests: that city compost and faeces cake are quick-acting nitrogen carriers.

Fig. 1 shows the average moisture percentage, the average amount of nitrate–nitrogen in mg. per 100 gm. of soil, the average monthly temperatures, and the crop and fallow periods for Experiment A.

Experiment B. Plots 81–100.—In this experiment samples were taken in 2 plots from each treatment every 2 weeks. The treatments are as described in the earlier part of this paper. Moisture percentages showed

very close agreement and are averaged together in one graph. Nitrate was graphed for each plot separately and grouped by treatments. Although not so close as the moisture figures, they nevertheless group themselves well together and could be averaged for each treatment. Fig. 2 shows the graphs of these 4 treatments (temperature and moisture being omitted as they are similar to those in Fig. 1). It can be seen that shortly after green manure (soya bean) was turned in on the unmanured plots (Aug. 19, 1940) nitrification became very rapid and these plots soon had much more nitrate than the others. By the beginning of the

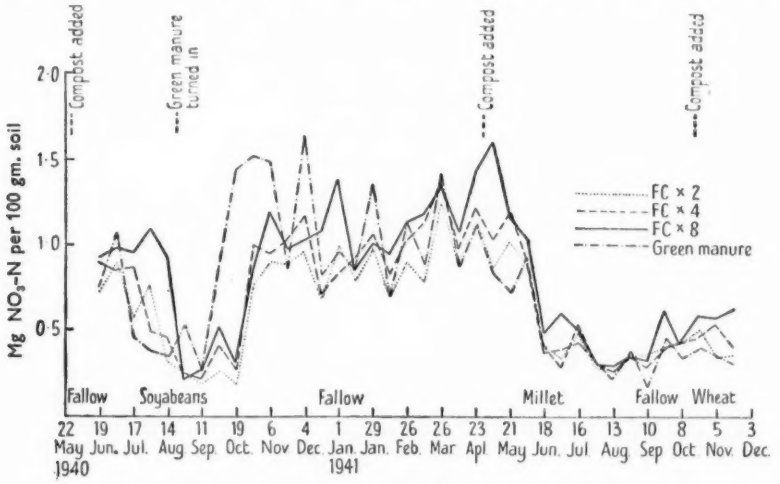

FIG. 2. Experiment B: Nitrate–nitrogen in Plots 81–100.

following spring, however, they were no better than the other plots and thereafter may be termed blank plots. A comparison of the graphs of the other 3 treatments shows that, on the whole, 4-times farm compost produced more nitrate than twice farm compost, and 8-times farm compost produced more nitrate still. It is doubtful, however, if these amounts are significantly different although they correlate very well with the crop yields obtained. On the graph it can be clearly seen how the soya bean and millet crops drained the nitrate from the soil. During the long winter fallow the amount of nitrate in the soil remained fairly constant.

Summary and Conclusions

A series of studies is described in which composts incorporating human faeces were tested on various crops together with inorganic fertilizers. These were carried out at Tsinan, Shantung Province, North China.

The main conclusions from these experiments are:

1. City compost, faeces cake, and ammonium sulphate are quick-acting nitrogen carriers; farm compost and pig-pen manure are slow-acting nitrogen carriers.

2. Farm compost gives the same response as pig-pen manure for much less faeces used. It would probably give more for the same amount of faeces.

3. Faeces cake gives a much larger response than pig-pen manure for about the same amount of faeces. Its nitrogen seems to be more readily available.

4. City compost seems to give highest returns per unit faeces used.

5. Limiting factors seem to be mainly moisture and nitrogen.

6. Nitrification studies accord well with crop tests.

7. The different fertilizer treatments do not appear to have had any influence on the moisture-holding properties of the soil.

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TWENTY YEARS OF SHORTHORN BREEDING IN EGYPT

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A COUNTRY like Egypt in which the production of field crops is of more importance than livestock production will, naturally enough, look to other parts of the world to make good the deficiency of animal products that the population needs, whether for food or other purpose.

A study of the official reports of the Egyptian State Customs extending over several years before the Second World War, showed that Egypt was paying annually, at pre-war prices, something like £5 m. for the purchase of live animals for meat, milk products, especially cheese, and inorganic fertilizers for the land. The neighbouring countries were the main sources of importation; and Chile supplied nitrate of soda. For the 20 years between the two world wars, therefore, Egypt has presented her neighbours and Chile with £100 m. due to her neglect of livestock. At the same time it must be emphasized that the whole structure of Egypt's economy depends on agriculture, and in the writer's opinion the agricultural position of the country will never be secure or safe unless animal production is recognized as of equal importance to crop production. One feature, although by no means the most important, is that the fertility of the soil can never be maintained if there is not enough farmyard manure to repair the damage done through years by the application of inorganic fertilizers, mostly of sodium salts.

In order, therefore, to induce the farmers to breed more livestock, and to establish the animal industry in Egypt to the extent desired, it was necessary to revise the whole situation in the light of the following two points:

1. The possibility of raising the standard of production in Egyptian livestock, and
2. Investigating the possibilities of introducing foreign breeds of animals into Egypt.

It is obvious that these two problems are inseparable and that by applying the tools of Bakewell, Egypt can attain a high standard of improvement in her livestock.

A comparison of the yields of the improved European breeds with those of Egyptian animals revealed how meagre the latter are, being, in general, not more than one-third to one-half of the former for all classes of production. It seemed, therefore, obvious that there was scope for European breeds in our farming practice.

With these objects in view work was begun in 1930 to breed pure Dairy Shorthorns, crossing Egyptian Dammietta cattle with them, and grading them up to Shorthorn blood. The experiments were conducted on the farm of the Faculty of Agriculture at the University, Giza.

The factors that influenced the choice of the Dairy Shorthorn breed for experimentation in Egypt were:

1. The breed is a dual-purpose one, thus supplying both milk and beef, and Egypt has a shortage of both these products. Also, the introduction of a dual-purpose breed makes it possible to limit the importation of foreign animals to one breed only.
2. The breed had been reported on good authority to be adaptable to change of climate and environment, thus reducing the risk of its introduction in a new country to a minimum.
3. Claims had been made that the breed had proved successful in different countries all over the world, some of which resemble Egypt in many respects.

Historical Survey

The usual course of crossing and grading up was followed in these experiments. In 1930, owing to difficulties in obtaining pure Shorthorns from abroad, the experiment was started with a bull borrowed from the Royal Agricultural Society of Egypt. This Society had a few Shorthorns which they thought to be a failure. The bull that was borrowed was a pure Dairy Shorthorn born in Egypt, its sire and dam both being pedigree cattle imported from England. This bull was 'Ibn Seraphina', dam 'Tockenham Seraphina' 34259 by 'Foxbury Wild Prince' 198761.

Nine Egyptian cows, of the Dammietta type, born and bred on the farm of the Faculty of Agriculture, Giza, were chosen to be served by this bull. Difficulties of service were clear from the very start, as the bull was too heavy for the cows. Only four conceived, the other five failing to do so despite repeated attempts. Two heifer calves and two bull calves were dropped after a normal gestation period. Names and dates of birth of the four calves are included in the following table for historic record.

TABLE 1

Name	*Sex*	*Date of birth*	*Dam*
Black Prince .	Male	8.8.1931	Mistika
Annie . . .	Female	10.9.1931	Khairia
Betty . . .	Female	26.9.1931	No Ten
White Star . .	Male	3.10.1931	Hamida

Another Dairy Shorthorn bull was borrowed from the Royal Agricultural Society of Egypt to serve the first generation crosses. He was 'Preshute Salaam', and in 1933 the bull 'Iford Cartoon 11th' was imported from England. He was used on the cross-bred and grade cows, and no bull did finer work in Egypt than he did. In all he sired 75 calves as follows:

Sex	½-*Shorthorn*	¾-*Shorthorn*	⅞-*Shorthorn*	*Pure Shorthorn*
♂	29	11	5	3
♀	14	8	4	1

Later three heifers were imported from England and it then became possible to produce pure-bred Shorthorns in Egypt. Since 1930, 11 pure-bred bulls and 9 cows have been born in Egypt on the University farm, and of these 3 bulls were given to the Ministry of Agriculture to start a herd on their own farms. At present, 3 stock-bulls are used in the University herd as well as to serve selected cows belonging to farmers in the area around Giza.

Milk Production

To measure the improvement obtained by crossing and grading up with Shorthorns, the figures in the following table have been calculated for all lactations. It should be noted here that throughout this experiment the Dammietta and cross-bred cattle were fed similarly and received the same management.

TABLE 2

	Egyptian Dammiettas	½-*Short-horn*	¾-*Short-horn*	⅞-*Short-horn*	$\frac{15}{16}$-*Short-horn*
No. of animals .	128	12	10	4	1
No. of lactations .	304	53	36	36	1
Mean milk yield, lb.	2,832	4,764	5,389	4,250	2,793
Standard deviation .	451·1	1,734·3	2,820·1	353·6	..
Coefft. of variability, per cent. . .	15·93	36·40	52·33	8·32	..

These figures are significant, indicating a marked increase in milk production of the Shorthorn grades over the Egyptian foundation stock. Details of each class of animal for each lactation are included in the following tables.

1. *Half-bred Shorthorns.*—In Table 3 milk yields of the first cross-bred generation of Shorthorn × Dammietta Cattle (i.e. half-breds) are compared with pure-bred Dammietta cattle and the percentage increase for each group of lactation yields is shown:

TABLE 3. *Milk Yields of Egyptian and Half-bred Cows, in lb.*

	I Lact.	*II Lact.*	*III Lact.*	*IV Lact.*	*V Lact.*
Dammietta . .	1,674	2,238	2,710·5	3,131	2,974
Dammietta × Shorthorn	3,917	4,393	5,861	6,036	4,750
Increase, per cent. .	133·4	96·3	116·2	92·8	59·5

These figures show that the percentage increase of the half-bred over the Dammiettas is greater in the first lactation than in any following one. Yet the increase is quite remarkable for any lactation, nearly doubling the milk yield in every case. The average percentage increase for all lactations obtained from the figures in Table 3 was 99·6 per cent. This result, obtained in one generation, would have taken generations to reach through selection from within Egyptian cattle. This point is clearly indicated, and cannot be stressed too strongly.

Moreover, individual half-bred animals reached striking figures that were unheard of in Egypt before. For instance, 'Annie' gave 9,047 lb. of milk, and 'Betty' gave 7,358 lb. of milk, both in their third lactation.

These findings are quite in agreement with the known facts of the factor-complex of milk yield in its inheritance, and indicate that heterosis probably played its part.

2. *Three-quarter-bred Shorthorns.*—Comparing the mean milk yields of the $\frac{3}{4}$-bred or first back-cross with those of the Dammiettas, as given in Table 2, it is seen that an increase of 90 per cent. in the mean yield has been obtained. The yields of the $\frac{3}{4}$-breds, though actually slightly higher than those of the $\frac{1}{2}$-breds, were obtained for fewer lactations than the latter and, as will be shown later, they were inferior in other respects.

3. *Other generations of grades.*—A study of the milk yields of the few $\frac{7}{8}$-Shorthorns and the $\frac{15}{16}$-Shorthorns does not show any superiority over the $\frac{3}{4}$-bred Shorthorns. Hence the inference is made that, although figures for only four lactations were available, no further improvement can be obtained by grading up to the Shorthorn breed.

Summarizing the results with the grade cattle, it is clear that:

(i) The greatest improvement is obtained in the milk yield of $\frac{1}{2}$-bred and $\frac{3}{4}$-bred generations.

(ii) The succeeding generations of back-crosses to Shorthorn bulls do not differ, for all practical purposes, to any significant extent in their milk yields.

(iii) Grading up to the Dairy Shorthorn in order to obtain a further improvement failed to justify its use.

4. *Pure Shorthorns.*—Average milk yield for all lactations of pure Shorthorns in our experiments was 5,982 lb. Average milk yield for each of the first few lactations was as follows:

TABLE 4. *Milk Yields of Pure-bred Dairy Shorthorns*

Lact.	*No. of cows*	*Mean yield, lb.*
1st	3	4,250
2nd	6	7,950
3rd	3	8,083
4th	2	4,500
5th	4	5,125
		Average 5,981·6

These figures are not outstanding although the pure-bred Shorthorns started with quite impressive yields, and therefore the record of every individual is given in the hope of throwing some light on the situation. The yields of the different lactations are included in Table 5.

The first three animals were imported, having had their first lactations in Great Britain. The best of these cows was Iford Perfection 18th, and her record of just under 16,000 lb. will probably remain in the history of animal breeding in Egypt as the highest milk yield.

TABLE 5. *Milk Yields of Pure-bred Shorthorns in lb.*

Lactation	*I*	*II*	*III*	*IV*	*V*
Iford Perfection 18th .	..	14,301	15,939	..	7,991
Redrice Darling 9th .	..	9,194·3	..	..	..
Histon Rosebud 8th .	..	9,439·8	5,792·8	..	3,105
Darlington's Duchess .	3,283·7	4,855·9	..	5,091·8	5,752·6
Red Rose . . .	3,795·0	2,602·6	3,593·1	3,824·8	3,436·5
Perfection II . .	5,720·4	(2,044)*	..	..	..

* Part lactation: the animal died before completing her lactation.

Yet the three imported animals show in common the following properties:

(i) Their milk yield is greater than that of the pure-bred cows born in Egypt.

(ii) They had their best yield in the first or second lactation following their arrival from Britain, after which their production decreased almost to half. There is only one explanation for this behaviour, that is, genotype and environment were not in complete harmony. To account for the conspicuous production of the imported animals right after their arrival in this country, it must be borne in mind that Egypt enjoys milder winters than Great Britain, and that the heat-regulating mechanism of the imported animals had not had time to be upset by the severe summers they had to experience later. When this last factor operated degeneration was inevitable.

The pure-bred Shorthorns born in Egypt gave milk yields that were not much higher than good native animals; their average for all lactations was 4,195·6 lb., as compared with 2,832·2 lb. for the Dammiettas, an increase of 48 per cent. in favour of the Shorthorns. Yet this advantage is deceptive because animals of pure Egyptian blood actually reached 6,000 and 7,000 lb. of milk, and the inference is therefore that breeding pure Dairy Shorthorns for the sake of milk production serves no useful purpose because they are surpassed by the half-bred crosses between them and Egyptian cattle, as well as by individual Egyptian cows and by buffaloes.

The Butter-fat in Milk

Butter-fat in the milk of cattle is not an important factor in the economy of Egypt, as it is replaced by that of the buffalo. A useful animal, in fact *the* dairy animal of Egypt, the buffalo has a yield of about 3,000 lb. per lactation with 7 per cent. butter-fat. In the improved herd of the Faculty of Agriculture the average milk yield is 4,200 lb.

Nevertheless, samples of the Shorthorn herd in question were taken for estimating the butter-fat by Gerber's method. The percentages of butter-fat were: Pure Shorthorns, 3·6; ½-Shorthorn, 3·8; ¾-Shorthorn, 3·9; ⅞-Shorthorn, 3·8; Egyptian Dammiettas, 4·0.

The first cross and grade cattle are indeterminate in their inheritance for butter-fat, which is quite in accordance with the factor-complex hypothesis.

TABLE 6. *Yields of Butter-fat, in lb.*

Animal	*Butter-fat*
Dammiettas	113·3
½-Shorthorn	181·0
¾-Shorthorn	210·2
⅞-Shorthorn	161·5
15/16-Shorthorn	211·8
Pure Shorthorns	215·0
Ordinary buffaloes	210·0
Improved buffaloes	294·0

Although Shorthorns, their crosses and grades, give more butter-fat than Egyptian cattle, they cannot compete with the improved buffaloes in this point—only the best pure-breds can do so, those with a milk yield of 7,500 lb. or over.

Beef Production

A study of the efficiency of the Shorthorn cross-bred and grade cattle was undertaken in this experiment.

Conformation.—Although Egyptian cattle are not of pure Zebu blood, yet some important Zebu characters dominate their conformation. These characters are of special significance in beef production, making Egyptian cattle, on the whole, unsuitable for this purpose. The cattle are high on the legs and at the hind-quarter and not deep in the body. There is hardly any doubt that unconscious selection for field-work and speed led to the evolution of this type of conformation many centuries ago.

How far did the genes of the Shorthorn improve this type for the production of beef? The first crosses and the grades without a single exception showed a beefy type, blocky conformation, heavy bodies, straight backs, and heavier hind-quarters—in comparison with the Egyptian parental stock. In short, they were intermediate between the Shorthorns and the Dammiettas, but nearer to the Shorthorn than the other type.

Weights taken at different stages of growth, at regular intervals of six months, are given in the following tables. Bull calves include those retained for breeding as well as steers.

TABLE 7. *Table of Weights for Bull-calves, in lb.*

	At birth	*6 months*	*12 months*	*18 months*	*24 months*
Dammiettas	58·5	237·3	339·7	575·6	746·0
½-Shorthorn	68·7	289·0	508·7	670·4	953·5
¾-Shorthorn	71·0	250·0	355·0	480·0	704·0
⅞-Shorthorn	66·0	254·0	409·0	410·7	..
15/16-Shorthorn	..	..	..	..	..
31/32-Shorthorn	62·2	286·0	289·0	497·3	..

TABLE 8. *Table of Weights for Heifer-calves, in lb.*

	At birth	*6 months*	*12 months*	*18 months*	*24 months*
Dammiettas . .	54·4	233·1	331·8	440·7	568·1
½-Shorthorn . .	66·4	271·4	500·6	605·9	824·4
¾-Shorthorn . .	67·4	241·8	358·7	488·3	649·4
⅞-Shorthorn . .	65·9	242·3	325·9	422·7	477·3
15/16-Shorthorn . .	64·4	240·0	331·9	420·0	559·4

In Table 9 the weights of both parental stocks and of the cross-bred are given for purposes of comparison.

TABLE 9. *Weights of Bull-calves, in lb.*

Age	*Dammiettas*	*Pure Shorthorns (born in Egypt)*	*Average of parents*	*Half-bred Dammietta × Shorthorn*
At birth .	58·5	70·8	64·7	68·7
3 months .	171·3	199·1	185·2	196·0
6 months .	237·3	344·8	291·05	289·0
9 months .	296·6	474·3	385·4	393·5
12 months .	339·7	550·6	395·2	508·7
15 months .	442·2	592·3	517·3	611·0
18 months .	575·0	709·5	462·3	670·4
24 months .	746·0	891·3	818·7	953·5
3 years .	998·0	1,067·0	1,032·5	1,265·0

At nearly every age the half-breds surpassed the average weight of both parental stock. Whereas this finding is in agreement with the inheritance of beef characters (the multiple factor theory), yet, all the same, the factor of heterosis and its effects are self-evident here.

Results of grading.—In comparing weights (Tables 7 and 8) of the grade-cattle with the Egyptian animals the following points are noted:

(i) The grades show little or no advantage over native cattle.

(ii) In every case the half-breds surpass the grades.

Hence the conclusion is drawn that grading up with Shorthorns served no purpose for beef production, but that the first cross produced a better beef animal in all respects than the Egyptian stock.

Incidence of Disease

The herd of Shorthorns, their half-bred crosses and grades, and the Egyptian cattle were all attacked by the more or less prevalent diseases of the country. Some cases of tuberculosis occurred among them. Foot-and-mouth disease of a mild type attacked the herd, those animals which were infected recovering in a few days. One or two suffered from mastitis. The one serious disease, however, that took a big toll of the Shorthorn herd, causing heavy losses, was tick fever.

TABLE 10. *Losses due to Tick Fever*

Class	*No. at time of infestation*	*Per cent. of infested animals*	*No. of animals that died*	*Per cent. of deaths due to disease*
Pure Shorthorns . .	14	71	7	50
$\frac{31}{32}$-Shorthorn . .	1	100	..	..
$\frac{15}{16}$-Shorthorn . .	5	60	2	40
$\frac{7}{8}$-Shorthorn . .	15	80	7	46
$\frac{3}{4}$-Shorthorn . .	22	50	6	27
$\frac{1}{2}$-Shorthorn . .	11	18	1	9

These figures indicate that a high degree of resistance is characteristic of the first-cross cattle only. All the higher grades and also the pure-breds are susceptible to tick fever. Egyptian cattle hardly ever suffer from the disease. It is obvious therefore that the greater the concentration of Shorthorn genes, the more prone to disease did the animals become, half of the pure-bred Shorthorns dying from tick fever.

This conclusion is important, being a deciding factor against the breeding of pure Shorthorns and their grades in this country. What applies to Shorthorns may apply to any exotic breed, and plans based on improvement of native stock through the infusion of foreign blood should aim at producing the first crosses only, but go no farther.

Summary

Experiments carried out for the last 20 years at the farm of the Faculty of Agriculture, Giza, Egypt, were planned to find out the genetic effect of introducing Dairy Shorthorns, crossing them with Egyptian cattle, and grading up to Shorthorns. The main purpose was to study characters of economic value, i.e. milk production, beef tendencies, incidence of disease, and adaptation to environment. The work involved the use of some 300 animals and the following results were obtained:

(1) The average milk yield of pure-bred Dairy Shorthorns for all lactations was a little more than twice that of Egyptian Dammietta cattle.

Imported animals kept their high standard of production for not more than two lactations after their introduction: thereafter their milk yield decreased almost by a half.

The pure-bred Shorthorns born in Egypt gave milk yields that were no higher than those of good Egyptian cows. The conclusion is drawn that the importation of Dairy Shorthorns for milk production served no purpose, unless immune strains could be built up.

Shorthorns, also, served no purpose for beef production in Egypt. They were prone to attack by tick fever, which took a big toll of them. They showed no resistance against the disease.

(2) The half-bred generation gave an average percentage increase in milk yield for all lactations of 99·6 per cent. over the Dammietta cattle. Their milk yield was higher than that of the pure-bred Shorthorns and of the succeeding generations of grades, except the $\frac{3}{4}$-bred.

For beef production the first crosses were of heavier weight than the average of both parents, and in conformation they showed a decided improvement over Egyptian cattle. They also showed a high degree of resistance to tick fever, and were more adaptable to the environment than the others.

(3) The first back-cross ($\frac{3}{4}$-Shorthorn) had an appreciable increase in milk yield over Egyptian cattle, but the grade cattle were inferior to the first cross in beef qualities, resistance to disease, and adaptability.

(4) Any proposal to improve Egyptian cattle by cross-breeding must, in the light of these experiments, aim at producing only the first-generation crosses and should not go beyond this. Pure-bred Shorthorn cattle can be useful only for the production of the half-bred generation.

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WHEAT PRODUCTION IN CANADA

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WITH PLATE 5

WHEAT is the most important farm crop in Canada; it comprises a larger area than the combined acreage devoted to oats, barley, rye, and flax, and it has twice the area of the combined acreage of hay and improved pasture. Wheat has a much greater total market value than any other crop, and a larger percentage is exported. This article deals with the soils, climate, acreages, yields, and the effect of certain agronomic factors connected with the production of wheat in Canada.

Land Areas and Climate

Although Canada covers an immense area of some 2·2 billion acres of land, the area of occupied farm-land in 1941 was only 175 million acres, or but 8 per cent. of the total. The land under cultivation was 89 m. acres, whilst that in unimproved pasture and range-land amounted to 52 m. An important question immediately arises as to how much additional land is suitable for cropping. Only a very approximate answer can be offered, but Dr. A. Leahey, in charge of the Canadian Soil Survey, has estimated that an additional 45 m. acres could be utilized.

Canada has immense areas unfit for agriculture. The great territory north of the nine provinces, of which only a mere fraction offers any agricultural possibilities, constitutes 40 per cent. of all Canada. The Precambrian Shield, mountain areas, and tundra comprise enormous areas, most of which seem unfit for agriculture. Soil surveys, conducted co-operatively by the Dominion and Provincial Departments of Agriculture and agricultural colleges, are gradually providing reliable information on the various soil types in the occupied parts of Canada.

The three prairie provinces of Manitoba, Saskatchewan, and Alberta comprise 62 per cent. of all the area under field crops and improved pasture, 82 per cent. of the unimproved or range pasture, and 97 per cent. of the summer-fallow acreage. These provinces are devoted largely to grain production, although they have also much livestock. The other provinces are engaged mostly in mixed farming and the production of special crops (Fig. 1).

The climate in the three prairie provinces, where wheat is the most important crop, is essentially continental. It is cold in the winter and reasonably warm in the summer, with precipitation ranging from about 12 to 21 in. a year. There is a great variation throughout this region, however, the climate ranging from semi-arid to sub-humid, depending not only upon the precipitation but on the temperature, evaporation, altitude, and other factors. Fortunately, most of the precipitation comes in the summer months during the growing season, but it is frequently erratic, with the occurrence of dry years seriously reducing yields.

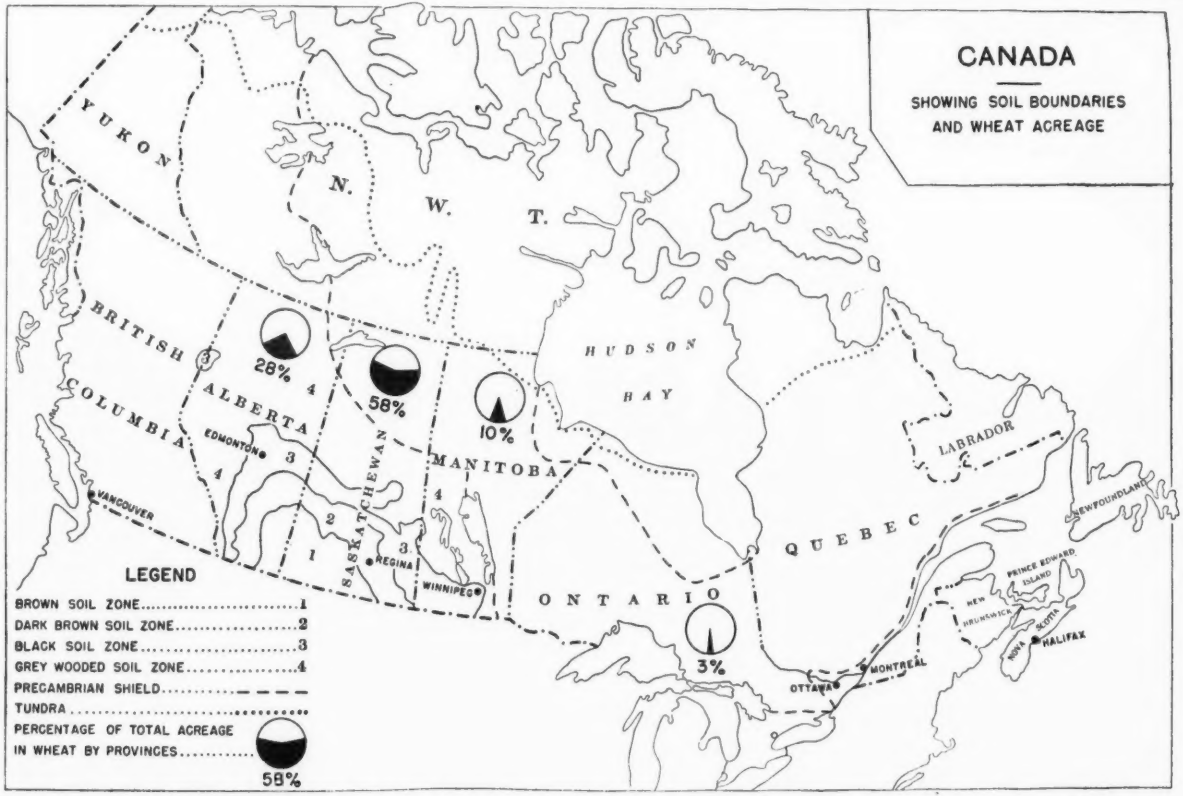

FIG. 1. Wheat production in Canada is located predominantly in the three prairie provinces of Manitoba, Saskatchewan, and Alberta. During the 5-year period from 1944 to 1948, Saskatchewan produced 58 per cent. of the entire acreage.

Sometimes two or more dry years follow each other in succession, giving rise to severe drought.

Table 1 gives the temperature and precipitation records at some representative places in the three prairie provinces and in the province of Ontario. This table shows the annual as well as the monthly mean temperatures for January and July, also the annual precipitation and the precipitation for the 5-month growing period from April to August.

TABLE 1. *Temperature and Precipitation Records in the Three Prairie Provinces and in Ontario*

Station	Yrs. av.	Temperature (°F.)			Precipitation (in.)	
		Jan. (mean)	July (mean)	Annual	5 months Apr.–Aug.	Total annual
Winnipeg, Man.	66	−3	67	35	12·31	21·19
Brandon, Man.	44	−1	65	35	11·56	18·68
Indian Head, Sask.	36	0	65	35	10·57	17·69
Regina, Sask.	55	−1	65	34	9·97	14·70
Saskatoon, Sask.	38	−1	65	34	9·06	14·55
Swift Current, Sask.	21	9	66	38	9·51	14·53
Manyberries, Alta.	14	13	69	41	7·11	11·72
Lethbridge, Alta.	41	17	64	41	9·55	15·76
Calgary, Alta.	55	13	62	38	11·27	16·65
Edmonton, Alta.	56	6	62	37	11·46	17·38
Fort Vermilion, Alta.	34	−11	61	28	7·08	11·89
Ottawa, Ont.	57	12	69	42	15·34	34·48
Toronto, Ont.	105	23	69	45	13·74	32·18

There is a much greater difference in the mean January temperatures among the various stations than in the temperatures for the month of July. Fort Vermilion, the most northerly station, has a July temperature only 8° less than that at Toronto, but the winter January temperature is 34° colder. The precipitation figures show considerable variation, especially between the stations located in the prairie provinces, as compared with those in the province of Ontario. Even within the prairie provinces the differences are quite marked. However, as is well known, precipitation data alone are quite inadequate to indicate the effectiveness of the precipitation on plant-growth. Other factors, and especially the amount of evaporation, play an important role. Thus, at Manyberries in southern Alberta, where the annual precipitation is only 11·72 in., there is insufficient moisture for successful wheat production, the land being devoted to grazing, but at Fort Vermilion in northern Alberta, with a very similar precipitation of 11·89 in., wheat grows very well. Although no evaporation data from a free-water surface in an evaporimeter tank are available for Fort Vermilion, the figures for the nearest experimental station at Beaverlodge, located some 250 miles to the south-west, for a 5-month period from May to September, show only 16·93 in. Manyberries, on the other hand, has 33·17 in.

Sufficient information is not yet available to define the northern limits of successful wheat production in Canada. Excellent results have been obtained over a long period of years on the Dominion Experimental

Sub-station at Fort Vermilion in northern Alberta, located in about latitude 59°. In fact, wheat has been grown near latitude 65°, but the records in these regions do not cover a long period of years.

Growth and Distribution of Wheat Acreages

Prior to the beginning of the twentieth century, wheat production in Canada was relatively small and located principally in Ontario. With the completion of the Canadian Pacific transcontinental railway in 1886, settlement began to expand rapidly. In 1905 the region formerly known as 'The Territories' was divided into the provinces of Saskatchewan and Alberta. The great expanse of rich, virgin prairie soils was open for homesteading.

In 1891 the total area of wheat in Canada was only 2,701,000 acres, of which over one-half was in Ontario. Ten years later Manitoba had an acreage in wheat one-third greater than that in Ontario. By 1911 Saskatchewan had almost twice as great an acreage as Manitoba. In fact, by this date Manitoba had reached nearly its maximum acreage in this crop and, excluding certain yearly variations, the acreage began to decline slightly. Ontario reached its maximum area under wheat of 1,448,000 acres in 1899 and then declined to less than half this amount, but in recent years there has been a slight upward trend.

Wheat acreages in Canada have increased steadily, especially following World War I. By 1921 it had reached 23,261,000 acres and, nine years later, 24,119,000 acres, an area practically identical with that grown in 1948. The largest acreage of wheat ever produced in Canada was in 1940, when 28,726,000 acres were grown, but on account of the enormous surplus and great difficulty of storage and marketing, the area dropped in 1943 to 16,849,000 acres.

The following data, taken from the Dominion Bureau of Statistics, show the acreage devoted to wheat in the various provinces of Canada during certain selected years.

TABLE 2. *Growth and Distribution of Wheat Acreage in Canada*

Province	*1891*	*1901*	*5-yr. aver. 1924–8*	*5-yr. aver. 1944–8*
Prince Edward Island	44,703	42,318	29,239	4,800
Nova Scotia	14,157	16,334	8,123	1,400
New Brunswick	17,306	26,990	10,931	2,440
Quebec	168,929	139,826	63,800	23,960
Ontario	1,430,532	1,487,633	856,228	730,000
Manitoba	896,622	1,965,200	2,260,634	2,473,200
Saskatchewan*	113,811	530,274	13,174,096	14,053,600
Alberta*			6,008,339	6,791,000
British Columbia	15,186	15,967	15,149	111,420
Canada	2,701,246	4,224,542	22,426,539	24,191,820

* Known as 'The Territories' until 1905.

Table 2 shows that Saskatchewan is the principal wheat-producing province in Canada, with considerably over one-half the total acreage.

The three prairie provinces of Manitoba, Saskatchewan, and Alberta have 96 per cent. of the total wheat acreage. Much of the wheat grown in these provinces is produced on summer-fallow, of which there were 19,889,000 acres during the last 5 years, from 1944 to 1948. Ontario, which in the early days grew over one-half the wheat, now grows only about 3 per cent. of the acreage. Production in the other provinces is practically negligible.

Wide Fluctuations in Wheat Yields

Great variations occur from year to year in the yields of wheat per acre in Canada. It is such an important crop to Canada, and the exports assume such a large proportion of the total world exports that the yield and size of the Canadian crop is of interest to many countries throughout the world. Attempts are made each year to predict the size of the Canadian crop as soon as possible, but it is not until the crop comes into head that any reasonably accurate estimate can be offered. Before the rust-resistant wheats were available, no estimate was safe even at that time.

The amount and distribution of the precipitation is now the principal cause of the variable annual yields. In a continental climate, such as in the prairie provinces, the variations are very great. Sometimes 2 or more dry years may follow each other in succession, giving rise to a protracted period when low yields may be experienced. Other climatological factors, such as frost, hail, and hot winds, though important in local districts, have not as great an influence. Insect loss and damage from plant diseases have also a more local influence.

In order to study the constantly changing picture of variable wheat yields in Canada, it may be helpful to present, in Table 3, the area and yield for each individual year over 41 years.

Thus the average yield of wheat for the 41-year period 1908–48 has been 16·2 bu. per acre. It has varied from 7·0 bu. in 1937 to 26·1 bu. in 1915. If attempts are made to group a number of years together in 5- or 10-year periods in an effort to study the trends in yields per acre, even these yields are subject to enormous variations, depending upon what years these periods cover.

Assuming the average yield of 16·2 bu. of wheat per acre and the average acreage of this crop during the last 5 years, from 1944 to 1948, to be 24,191,820 acres, the total annual production would average 391,907,484 bu. From this total must be subtracted the domestic utilization for seed, flour, and feed, perhaps averaging about 150 m. bu. and ranging from approximately 100 to 175 m. bu., before the amount available for export is known. This would leave approximately 241 m. bu. for export, provided a normal crop were produced.

However, in good years the wheat crop may reach as much as 566·7 m. bu., as was harvested in 1928, or 556·7 m. bu. as harvested in 1942. The amount of wheat available for export from the crops grown in these years might approach 400 m. bu. On the other hand, in a poor year such as 1937, when only 180·2 m. bu. were produced, a very small quantity would be available for export from the crop in that year.

TABLE 3. *Acreage, Yield, and Total Production of Wheat in Canada, 1908–48**

(Areas and total yields are given in millions, rounded off to the first decimal place)

Year	Area, acres	Average yield, bu.	Total yield, bu.	Year	Area, acres	Average yield, bu.	Total yield, bu.
1908	6·6	17·0	112·4	1929	25·3	12·1	304·5
1909	7·8	21·5	166·7	1930	24·9	16·9	420·7
1910	8·9	14·9	132·1	1931	26·4	12·2	321·3
1911	11·1	20·8	231·2	1932	27·2	16·3	443·1
1912	11·0	20·4	224·2	1933	26·0	10·8	281·9
1913	11·0	21·0	231·7	1934	24·0	11·5	275·8
1914	10·3	15·7	161·3	1935	24·1	11·7	281·9
1915	15·1	26·1	393·5	1936	25·6	8·6	219·2
1916	15·4	17·1	262·8	1937	25·6	7·0	180·2
1917	14·8	15·8	233·7	1938	25·9	13·9	360·0
1918	17·4	10·9	189·1	1939	26·8	19·5	520·6
1919	19·1	10·1	193·3	1940	28·7	18·8	540·2
1920	18·2	14·4	263·2	1941	21·9	14·4	314·8
1921	23·3	12·9	300·1	1942	21·6	25·8	556·7
1922	22·4	17·8	399·8	1943	16·8	16·9	284·5
1923	21·9	21·7	474·2	1944	23·3	17·9	416·6
1924	22·1	11·9	262·1	1945	23·4	13·6	318·5
1925	20·8	19·0	395·5	1946	24·5	16·9	413·7
1926	22·9	17·8	407·1	1947	24·3	14·0	340·8
1927	22·5	21·4	479·7	1948†	24·1	16·2	391·0
1928	24·1	23·5	566·7	Average 41 years		16·2	

* From Dominion Bureau of Statistics. † Estimated.

In addition, there would also be available for export the amount of the carry-over on farms and in elevators throughout the country. This carry-over has averaged 175 m. bu. over the last 25 years, and has ranged from 24 m. bu. on July 31, 1938, to 595 m. bu. on July 31, 1943. A combination of a poor crop year with a low carry-over, it is clear, results in a very small quantity of wheat being available for export.

The most disastrous period ever experienced in Canada was during the 10 years of drought and soil drifting, from 1929 to 1938, inclusive, when the average yield was 12·2 bu. per acre. For the extreme 5-year period, 1933–7, it was only 10·1 bu. However, the next 5 years, 1938–42, were good and the yield was 18·5 bu., reaching 25·8 bu. in 1942. Another extremely dry 5-year period occurred earlier, from 1917 to 1921, when the average yield was only 12·8 bu. per acre. Obviously these yields are so variable that it is impossible to estimate yield trends from these data, or to gauge whether the productivity of the soil is changing materially.

In the province of Saskatchewan, where over one-half the total acreage of wheat in Canada is grown, the fluctuations in yield are more extreme. For the 10-year period, 1929–38, the average provincial yield was only 9·6 bu. per acre, and for the extreme 5-year period, 1933–7, it was only 7·6 bu., dropping to 2·7 bu. in 1937. Following this dry period, a series of good years was enjoyed, with the average yield in 1942 reaching 24·7

bu. per acre. It is natural that good years should arouse the greatest optimism whilst years with crop failures should cause gloomy depression.

If smaller areas than a province are considered, such as a municipality or crop district, variations are even more extreme. Frequently good yields may be obtained in one part of a province when poor crops or even complete failures are experienced elsewhere. The Canadian Department of Agriculture, in order to protect the farmer when wheat yields fall to certain prescribed levels, makes certain payments under what is known as the Prairie Farm Assistance Act. All farmers in the prairie provinces contribute 1 per cent. of the value of their wheat crop, which defrays about one-third of the cost, the Government providing the remainder.

Comparisons between the Wheat Crops of the U.S.A. and Canada

As the wheat crops of the United States and Canada come from one continent, and as both crops enter into extensive domestic and export trade, it may be of interest to offer a brief comment on some points of similarity and contrast. The U.S.A. has a much larger wheat acreage than Canada, varying from two to three times as much. However, as the population is about eleven times greater, the proportion of the total wheat crop available for export is very much less. The actual amount exported from both countries has varied widely, sometimes one country exporting more than the other.

The yield of wheat per acre is somewhat higher in Canada, 16·2 bu. as an average of the last 41 years, as compared with 14·3 over a period of 61 years in the U.S.A. However, the Canadian wheat yields are subject to much wider fluctuations from year to year: the average yield in Canada has ranged from 7·0 to 26·1 bu., in the U.S.A. only from 11·1 to 19·5 bu. Although these differences in yield per acre may seem small, when they are multiplied by the total acreages in wheat they amount to an enormous difference in the total number of bushels.

In Canada wheat-growing is concentrated in the three prairie provinces. In the U.S.A., although Kansas and North Dakota are the largest wheat producers, there are over a dozen additional states with quite extensive acreages. Whilst the average yield of wheat per acre is slightly higher in Canada than in the U.S.A., a much higher percentage is grown on summer-fallow land and, hence, if this land were also taken into consideration, the yield would be less. In Canada over 90 per cent. of the crop is hard spring wheat, whilst in the U.S.A. there are large quantities of both autumn and spring wheat, with perhaps over three-quarters seeded in the autumn. Canada has a much larger percentage of higher protein wheat.

Plant-breeding Achievements

Wheat production in Canada owes much to the plant-breeder. It is, perhaps, safe to say that scientific agriculture has accomplished greater financial benefits in this field than in any other. Certainly the great wheat crop from this country has originated almost entirely from varieties of seed developed and improved by plant-breeders. Many hundreds of varieties, both Canadian and foreign, have been tried under various soil and climatic conditions.

Marquis wheat was the first outstanding variety developed by the Dominion Experimental Farms. It originated from a cross made by Dr. William Saunders, in 1892, between Hard Red Calcutta and the leading Canadian wheat, Red Fife. It was distributed to farmers about 1908, and by 1915 this variety had taken the lead over all others. By 1920 it constituted 90 per cent. of the wheat acreage in Canada and 60 per cent. of the spring wheat acreage in the U.S.A. It was an excellent wheat, 6–10 days earlier in maturity than the previous Red Fife variety, heavier yielding, less shattering, stronger straw, and with unexcelled baking quality.

However, Marquis wheat had one serious defect. It was susceptible to rust. Every few years, especially during years when the precipitation favoured a heavy growth, rust would seriously damage or almost completely destroy the wheat crop over the greater part of the prairie provinces. Only the western part of Alberta was completely free from this disease. Plant-breeders started trying to breed resistant varieties. A laboratory of cereal breeding was established in 1925 by the Dominion Experimental Farms at the Manitoba Agricultural College, Winnipeg, in which plant-breeders and plant-pathologists combined their efforts to overcome this trouble.

The first rust-resistant wheat to be available to Canadian farmers was Thatcher, a variety originating at the University of Minnesota. Thatcher wheat was distributed first in 1935, and soon became the most important variety, reaching its maximum acreage about 1946. Canadian rust-resistant varieties, Renown and Regent, developed by the Dominion Experimental Farms, and Apex by the University of Saskatchewan, have been distributed and are used in various parts of the prairie provinces. Regent is predominant in Manitoba, but a more recent variety, Redman, has possibilities of replacing Regent on account of its higher yield and greater disease-resistance. To-day, only about 10 per cent. of the wheat is of the Marquis variety, which is grown in regions not affected by rust.

In addition to rust-resistance, plant-breeders have developed wheat varieties with other important characteristics. As production has extended to more northern areas, it has become necessary to develop varieties combining existing agronomic qualities plus earlier ripening. A recent variety, Saunders, gives considerable promise in this regard. In some areas an insect known as the Wheat Stem Sawfly (*Cephus cinctus* Nort) causes considerable damage, tunnelling through the stems, filling them with a sawdust-like material, and causing the stems to break off close to the ground. Plant-breeders have met this problem by breeding a solid-stemmed wheat, Rescue, which is resistant to the sawfly. This variety gives very good results in regions affected by this insect, and is grown extensively in these particular areas. In eastern Canada a winter wheat known as Rideau is being grown in regions where the common variety, Dawson's Golden Chaff, is not sufficiently winter hardy.

These new and improved wheat varieties have added many millions of dollars to the Canadian farmer and the Canadian economy. It is

difficult to estimate this benefit exactly, but it is possible to make an approximation. The area under wheat is known to average in recent years about 24 m. acres. The amount of the increased yield per acre and the improved quality must be estimated. During the years when Marquis wheat was the leading variety, its yield exceeded that of the Red Fife variety perhaps by about 3–5 bu. per acre. The recent rust-resistant varieties yield more than Marquis even in non-rust years, whilst in rust years the Marquis variety is a failure. It would seem quite safe to estimate that over a period of years the new wheats would give an increased yield of about 5 bu. an acre over the earlier unimproved varieties. This would be equivalent, on 24 m. acres, to 120 m. bu. a year. The science of plant-breeding has already accomplished much for Canadian agriculture, and in the future it will continue to provide the solution to a growing number of problems in crop production.

Effect of Grain-farming on Soil Productivity

Theoretically, grain-farming would seem to be harmful to the productivity of the soil. The large acreage of summer-fallow exposes the soil to much greater erosion both by wind and water, and to the greater oxidation of the organic matter. The almost complete absence in most regions of grass and legume crops reduces the organic matter and the nitrogen supply. Very little farm manure is applied. At first glance it would seem that there could be no doubt but that this system of farming was distinctly injurious to the land. However, the problem is complicated, and there are many angles to it.

It is frequently asked whether the wheat yields in Canada are increasing or decreasing. This is a very difficult question to answer definitely; there are so many factors involved that it is hard to find any suitable basis for comparison. First, the individual seasons vary considerably from year to year, giving rise to widely fluctuating yields. Even several successive good or poor years may occur at irregular and unpredictable intervals. The percentage of wheat production on virgin prairie soil has changed over a period of years. There has been a great shift in the amount and per cent. of acreage from one province to another. The occurrence of rust, insects, and frost is very irregular. There is also the unquestionable beneficial influence of improved and rust-resistant varieties of wheat which have undoubtedly had the effect of increasing yields. These variable factors make it difficult to measure any change in the yields per acre, considering the country as a whole. It is only by measuring the results on Experimental Farms that some of these factors can be eliminated. Experiments conducted by the Dominion Experimental Farms give very useful information on this important problem.

Variable Effects of Hay Crops in Crop Rotations

The most common crop rotations in the prairie provinces consist of summer-fallow followed by one or more years of grain. In the drier regions of the brown-soil zone a 2-year rotation of summer-fallow and wheat is used. In the dark-brown zone a 3-year rotation of summer-fallow, wheat, and wheat or coarse grain is extensively practised. In the

black-soil zone, and where the precipitation is more favourable, a longer rotation is often adopted, the summer-fallow being followed by 2, 3, or more years of grain, perhaps including barley or grain cut green for feed in an effort to control weeds. Hay and pasture crops are rarely seen in the drier parts of the prairie, only 3 per cent. of the total cultivated acreage in the three prairie provinces being devoted to these crops.

Some people from humid countries are critical of these cropping practices. They condemn these methods as mining the soil. They predict an impoverished soil with uncontrolled erosion. They prophesy the ultimate ruin of the country. However, they base their opinions on experience gained under very different conditions, which are scarcely applicable to semi-arid regions.

The Dominion Experimental Farms began in 1911 a comprehensive series of experiments at several branch Experimental Stations in order to determine optimum crop rotations. The results have given useful information. They show that in the drier brown and dark-brown soil zones the growing of grass and legume crops from 1 to 3 years has had no beneficial effect. In fact, if anything, this practice has been more detrimental to the yields of wheat than if it followed a grain crop. The yield of hay, also, has been low, only about one-half to one ton per acre, and of poor quality. Economically as well as agronomically, hay crops in a rotation in these dry regions are a complete failure. Whether better results might be obtained from leaving the hay for a longer number of years in an attempt to simulate the virgin prairie sod is not known, as the original experiments did not cover this point. Experiments are now in progress which may provide information on this question, but many years will be required to obtain the answer.

Strange as it might seem, on the other hand, the use of hay in crop rotations has given remarkably beneficial results in the black-soil zone where there is favourable precipitation, such as on the Dominion Experimental Station at Lacombe, Alberta. Even on a rich soil with a nitrogen-content ranging from 0·35 to 0·50 per cent., the inclusion of a mixed alfalfa and timothy hay crop in the rotation has greatly increased, in some cases doubled, the yields of subsequent grain crops. However, it has not yet been learned to what extent this wonderful result is due to the control of weeds, especially wild oats, by the hay crop in the mixed-farming rotation, rather than to its effect on the soil. Experiments are now in progress to secure this information. In the grey wooded soil zone, the use of legume hay crops in the rotation, as well as the application of sulphur and phosphorus fertilizers, is a prerequisite to successful crop production. However, very little wheat is as yet grown on the grey wooded soil zone.

The Use of Farm Manure and Commercial Fertilizer

Before considering the use of manure and fertilizers for the production of wheat in Canada, it should be remembered that 96 per cent. of this crop is grown in the three prairie provinces, and that this region has a climate ranging from semi-arid to sub-humid. Farmers keep very little livestock, and hence have practically no manure in the region where most

of the wheat is produced. Experiments show that manure in the drier areas gives no increase in the yields of crops. As the moisture conditions become more favourable, some benefit is obtained, until in more favourable areas the results are similar to those secured in humid regions. Farm manure should be applied to the lightest and poorest land and to any areas subject to soil drifting.

The use of commercial fertilizers, essentially a nitrogen-phosphorus fertilizer of high analysis, started in the prairie provinces about 20 years ago. The application of small quantities, 25–50 lb. per acre, of 11–48–0 fertilizer with a combination grain and fertilizer drill, placing the fertilizer in the drill row, has given considerably increased results in some regions. Here again the dry areas give little or no response whatever, but the districts with more favourable moisture conditions give quite profitable returns.

Increases of from 2 to 10 bu. of wheat per acre have been obtained at several experimental stations on summer-fallow land. Greater increases are obtained when the fertilizer is applied with wheat seeded on summer-fallow than where wheat follows wheat. On some of the rich black soils in the areas with better moisture where good results have been obtained from legume hay crops, increases of 10 or more bu. per acre have been secured from an application of 50 lb. per acre of 11–48–0 fertilizer. It is clear that the benefit from the use of commercial fertilizers depends upon the climate, soil zone, soil type, and the fertility of the individual field to which it is applied.

The natural fertility of the grey wooded soils in the northern regions is much poorer than that of the brown and black soils. They cannot be farmed successfully by the easy methods which are possible on the latter soils. Nevertheless, this is the region where most of the future expansion of agricultural development will take place.

Remarkable results have been obtained on some of these grey wooded soils by a combination of the use of sulphur, phosphorus, and the growing of legume crops in the rotation. In some cases, grain yields have been more than doubled by the use of these methods as compared with a simple summer-fallow and grain rotation. Unfortunately, similar results have not been obtained on all grey soils, and additional experimental work will be needed to learn what methods are most suitable under these varying conditions.

The total quantity of commercial fertilizer used in the three prairie provinces in 1946 amounted to 31,000 tons, of which 25,000 tons consisted of 11–48–0. Assuming a rate of application of 25 lb. per acre, the latter fertilizer would cover 2 m. acres, which is only one-twelfth of the wheat acreage alone, without including the acreage in other crops. Even considering that there is a large area on which it is too dry to use fertilizer, it is clear that there is a large area which does not now, but could, use fertilizer to great advantage, and that some areas could use a larger rate per acre. The future should see a very considerable expansion in the use of commercial fertilizers in the prairie provinces, especially if the price of wheat remains at a reasonably high level.

Tillage Practices and Soil-erosion Control

Surface tillage rather than ploughing has been practised in the prairie provinces of Canada for many years. When the prairie was first settled, practices were used similar to those followed in older, humid countries. The mould-board plough and autumn ploughing were thought to be prerequisites of success. Both experience and experiments have proved that surface tillage in spring is superior.

The cultivator was first used for surface tillage, but it gave difficulty from clogging trash. To-day, the use of a combination one-way disk and cultivator or, in the drier regions, the new blade cultivator, is standard practice. (Fig. 2, Plate 5.) Fewer operations are given now on the summer-fallow, the object being to control weeds and to leave sufficient trash on the surface to control soil drifting.

In some dry years soil drifting becomes serious. It is particularly grave when 2 or more dry years follow successively. In such circumstances there is very little stubble or trash to help check the drifting. Emergency methods must then be used, as surface tillage merely pulverizes the surface, rendering it even more susceptible to drifting. Deep ploughing or listing must then be done to create larger lumps of soil which for a time retain their size and hold against the drifting.

Summer-fallow land is most liable to drift, and, as there are some 20 m. acres of such land in the prairie provinces, it constitutes a serious menace. If winter wheat could be grown, the problem would be largely overcome, but winter wheat is not sufficiently hardy except in a very small fraction of the area. The use of a cover crop, i.e. the planting of a light seeding of wheat or oats in late summer, is successful in regions where it can be grown, but this is only in a very small section of western Alberta. In that region this practice has proved effective, not only in controlling soil drifting, but in providing autumn pasture without reducing the yield of the wheat crop the following year.

Strip-farming is followed extensively in southern Alberta and, to some extent, in certain other parts of the prairie provinces. It consists in alternating wheat and summer-fallow in strips about 16 rods wide at right angles to the prevailing winds. The strips of grain and the stubble on the summer-fallow during the spring help to check the moving soil. The only weakness with strip-farming is when, after 2 or more successive dry years, there is little stubble to offer any resistance to the wind. When strip-farming is combined with surface tillage and other control methods, the combination is fairly effective in controlling drifting.

The Canadian Department of Agriculture introduced a programme in 1935, under the Prairie Farm Rehabilitation Act, designed to alleviate the losses suffered by drought and soil drifting. This programme includes water-conservation, irrigation projects, re-grassing of abandoned farm-land, community pastures, tree-planting, and methods for the control of soil erosion.

Wheat production has become highly mechanized. The tractor and combine have largely replaced the horse and threshing-machine. This

change has greatly increased the acreage which one man can handle, and at the same time has very appreciably reduced the cost.

Future Prospects

No person can foresee the future and predict the development of wheat production in Canada. However, it is possible to study the past and then hazard some opinions about the future. Who could have foreseen 50 years ago the enormous growth of wheat production in Canada, its shift from eastern Canada to the prairie provinces, and its change from horse to tractor power? Who would have thought that one man alone could handle 600 acres or more of land?

The future may see considerable change in wheat acreages. It will depend upon wheat prices and economic conditions. World requirements rather than Canadian needs will decide this question. If world population increases more rapidly than food production, as some authorities believe, larger quantities of wheat will have to be produced, necessitating the use of land now considered sub-marginal. If larger acreages of wheat should be required, a considerable expansion is possible, but it will have to come chiefly in the less fertile, grey wooded soil zone, where the quality of the wheat produced would not be as high. Some increased acreage, also, could come by substitution for crops in other areas.

Wide fluctuations in the yields per acre from year to year must be expected. The introduction of rust-resistant wheats has already reduced somewhat the extent of this fluctuation, but they can never eliminate it. If the wheat acreage should be extended to the less fertile grey soils, located in the sub-humid regions, the incidence of drought would be somewhat reduced but by no means overcome.

Some increases in the yields of wheat per acre may be expected through plant-breeding, insect and disease control, as well as by improved soil, tillage, cropping, fertilizing, and other practices. Agronomic studies on various soil types under various climatic conditions should provide more reliable information applicable to more local agricultural conditions. Mechanization would almost seem to have reached its limit in the production of this crop, but no doubt some improvements can be introduced. Scientific agriculture should play an important role in securing the maximum production of wheat consistent with the requirements and at the lowest possible expenditure of capital and labour.

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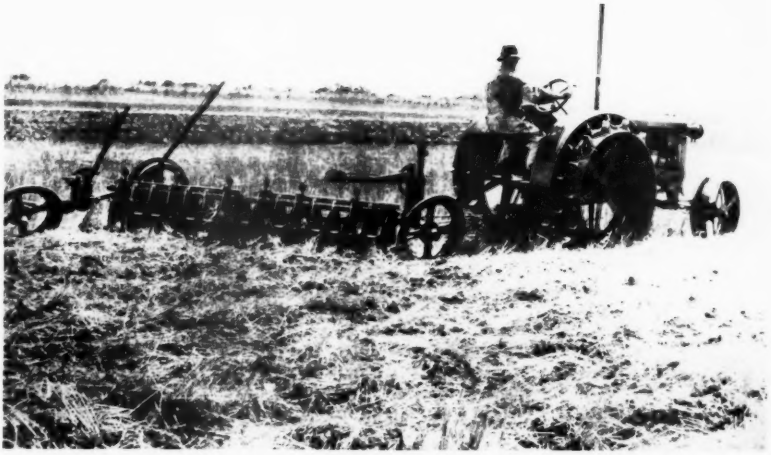

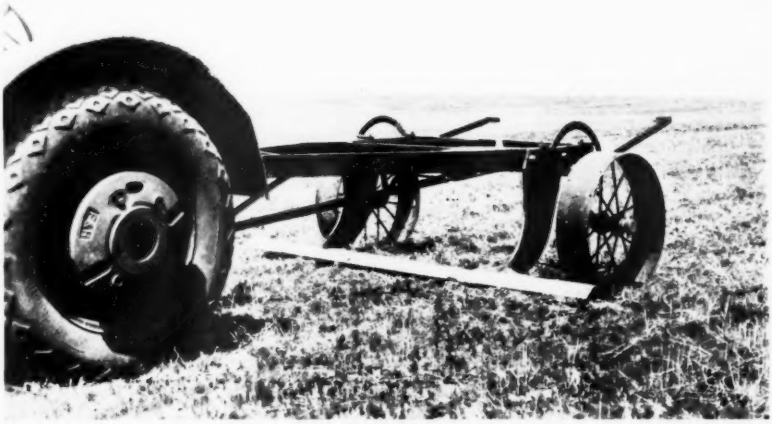

FIG. 2. Surface tillage rather than ploughing is usually employed in the production of wheat. The cultivator and one-way disk (upper photograph) are the most common implements. The Noble blade (lower photograph) has recently been found quite effective in the drier regions as it leaves all the trash on the surface

SOME SEASONAL OBSERVATIONS ON THE GRAZING HABITS OF SHEEP

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AN examination of the behaviour of farm animals provides a scientific basis for the study of the stockman's art. Hammond [1] has recently emphasized the need of further research in this field.

The value of such studies in relation to methods of pasture management has long been recognized; in 1926 Stapledon and Jones [2] stressed the intimate connexion between the pasture complex and the animal complex, and suggested that a study be made of the grazing habits of sheep along the lines indicated by them at Aberystwyth. Since their results were obtained from observations on only two sheep during two 24-hr. periods, the value of their work lies, as they indicated, in the suggested lines of inquiry, and no attempt was made by them to propound new facts.

Investigators of the pasture complex [3, 4, 5, 6, 7, 32] have studied this relationship of animal to plant in considerable detail, but less attention has so far been paid to it by animal husbandmen.

Levy [8] of New Zealand has shown how a knowledge of the grazing habits of dairy cattle has helped to eradicate feed-flavours in milk. Doran [9] and Stoddart and Rasmussen [10] have shown how observations on sheep habits can help to increase efficiency of management on American ranges. Nichols [11] has described how observations on sheep behaviour played a most important part in solving the problem of saving some drought-stricken stocks in Western Australia. Johnstone-Wallace [12] and Johnstone-Wallace and Kennedy [13] have shown how improved methods of pasture management may result from information on the grazing habits of beef cattle. Some interesting climatological studies on sheep have recently been conducted by Bosman [34] in South Africa.

However, none of these workers has attempted to ascertain the general behaviour pattern of the grazing sheep, or tried to show how this may be altered by seasonal changes throughout a full year. As has been indicated recently, 'our knowledge of the whims and reactions of the grazing animal—his psychology in short—is limited and elementary in the extreme' [14], and it was therefore as a contribution to this knowledge that this research was undertaken. The scope of the present study was purposely limited in order to eliminate sources of climatic and biotic variation. It is intended that the results should serve as a basis for future detailed consideration of these variants.

Experimental

To determine with accuracy the behaviour of sheep at pasture there is only one available technique—that of direct and continuous observation.

[1] This work was carried out under the terms of a Ministry of Agriculture Postgraduate Scholarship.

This method has previously been used and described by Cory [15], who reported in considerable detail the behaviour of cattle, sheep, and goats on ranges in Texas. The value of his work was, however, reduced by his mistaken assumption that once sheep lie down to rest in the evening they will stay in the same position until next morning. 'This assumption', he points out, 'is based on the more or less common knowledge that such is the case, and it receives support from the observations by Ellingboe [16] that animals having gone to rest will stay at rest during the night.' Unfortunately objection may be made on the same grounds to the behaviour studies of Doran [9] and Hodgson [17]. Ellingboe [16] did not actually observe the habits of range animals, and Stapledon and Jones [2], Seath and Miller [33], Atkeson *et al.* [35], Shepherd [18], Johnstone-Wallace and Kennedy [13], and Tribe [19] have all shown that cattle and sheep at pasture are, in point of fact, very liable to graze and move about considerably during the night. Blaxter [20] also reported that housed cattle never sleep for long periods, they are restless and, in the early morning, like to feed. Therefore, since it was evidently necessary to make observations over 24-hr. periods throughout all seasons of the year, it was essential to select a pasture in which the animals would be in constant sight of an observer situated in a position which would provide both adequate comfort and protection from a capricious climate. A pasture adjoining some buildings was chosen since these afforded suitable quarters for the observer, and the field, being but 1 acre in size, provided facilities for accurate recordings, particularly of the distance the sheep walked. Had the acreage been greater it is very probable that the distance travelled would have been increased [19, 21], and it is possible that there would have been smaller differences in the times spent grazing and lying down. Since, however, the flock used in the observations consisted of only 5 sheep, the area provided sufficient scope for the general expression of their normal behaviour. Unfortunately, the growth of the pasture was not always as advanced as was hoped, and in few cases a small amount of supplementary feed had to be provided. This was probably not sufficient to alter the overall picture.

Since the present study represents an attempt to determine the general features of sheep behaviour on lowland pasture and to trace the influence of seasonal changes on them, much care was taken to eliminate the effect of possible alternative influences.

The breed of animal used was always the Cheviot, and before each period of observation all animals were given ample opportunity to settle down in the experimental paddock. They were of similar age, sex, and previous history.

Observations were continued over 12 consecutive months beginning October 1946, and on each occasion care was taken to select a 24-hr. period during which climatic conditions typical of the particular time of year were expected. In this way the effects of unusual climatic variations were avoided. Meteorological information,[1] which was subsequently

[1] The details of this information may be obtained, on request, from the Reid Library, Bucksburn, Aberdeen.

obtained from Aberdeen Observatory, included hourly recordings of temperature, rainfall, and wind, for each period of observation, and testified to the reliability of the meteorological forecast. In only one case did the mean temperature of the observation period differ more than 3° absolute from the mean temperature for the month; this was in March when the monthly mean was 77·7° and the mean of the observation period was 69·6°. Rain occurred only during the observation periods made in January, March, April, and May. In January and March there were 5·8 and 3·8 in. of rain respectively, most of which fell between 19·00 and 07·00 hrs. in both cases. During the January and February observations there were slight falls of snow between 07·00 and 19·00 hrs. The speed of the wind in every period of observation was slower than the monthly mean, and the only time the period mean reached 10 m.p.h. was in April, when the speed was uniformly high throughout the 24 hrs. Between 07·00 and 19·00 hrs. in the September observations the wind averaged 12 m.p.h., but the average for the 24-hr. period was only 8 m.p.h.

Before each period of observation one animal, chosen at random, was clearly marked on its head, sides, and rump; the distance this individual moved and the times it devoted to the various functions were then continuously recorded. In confirmation of the work of Stapledon and Jones [2], and Jones [5], it was found that although the records were from a single animal on each occasion they did, in fact, reflect the actions of the experimental group. In January, February, and March recordings were made simultaneously for the 5 animals. The data, shown in Table 1, show that the variations between the times individuals devoted to grazing and resting were never large.

TABLE 1. *Comparison of the Behaviour of Five Individuals in January, February, and March, 1947*

	A		*B*		*C*		*D*		*E*	
	hr.	*min.*	*hr.*	*min.*	*hr.*	*min.*	*hr.*	*min.*	*hr.*	*min.*
					January					
07·00–19·00 hours:										
Grazing	7	20	7	10	7	17	7	1	7	13
Resting	4	12	4	20	4	15	4	25	4	10
19·00–07·00 hours:										
Grazing	2	10	2	8	2	15	2	0	2	13
Resting	8	50	9	0	8	56	8	48	9	2
					February					
07·00–19·00 hours:										
Grazing	7	56	7	48	7	52	7	56	7	59
Resting	3	40	3	44	3	37	3	46	3	36
19·00–07·00 hours:										
Grazing	1	53	1	48	1	57	2	0	1	55
Resting	9	10	9	13	9	11	9	6	9	8
					March					
07·00–19·00 hours:										
Grazing	7	30	7	27	7	31	7	35	7	33
Resting	4	0	4	3	3	58	4	3	4	1
19·00–07·00 hours:										
Grazing	2	12	2	15	2	6	2	8	2	13
Resting	9	0	9	2	9	10	9	4	8	58

No observations were made on completely moonless nights, since the use of artificial light would have been necessary and would possibly have disturbed the sheep. The observer's eyes soon became adjusted to the darkness even when the moon was low, and it was possible to dispense altogether with the use of a flash-lamp. Recordings were made by a single observer and began at either 07·00 or 19·00 hrs. and continued for 24 hrs. The time spent by the animals in performing the various functions was measured with the aid of a clock. A stop-watch was not required, since differences in seconds are negligible when dealing with total times in terms of hours. The method described by Johnstone-Wallace and Kennedy [13] was used to record the distances travelled; numbered stakes were arranged in the field at 10-yard intervals and the movements of the animal recorded on graph-paper in relation to the position of the stakes.

The activities of the sheep were considered under three headings:

Grazing: the total time the animal spent in the selection, collection, and consumption of food. It was impossible to differentiate between these sub-activities.

Resting: the total time the animal spent lying down, no matter whether it was chewing the cud or not.

Idling: the total time devoted to the various other activities, such as boxing, rubbing or scratching, loitering, just standing, and travelling. (Where travelling was expressly concerned with the collection of food it was included under grazing.)

Unfortunately since it was impossible to record the amount of time spent chewing the cud during darkness, or even twilight, the figures for ruminating during daylight have had to be ignored since, by themselves, they can be of little value. Also no mention is made of the frequency of defaecation and urination since the excretory functions of the sheep, unlike those of cattle, are difficult to observe in daylight, and quite impossible after dark, and the recordings collected may therefore have been misleading.

The time (G.M.T.) of sunset and sunrise at Aberdeen are given below:

	Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
Sunset (p.m.)	3·35	4·33	5·40	6·47	7·52	8·51	9·7	8·23	7·7	5·44	4·24	3·31
Sunrise (a.m.)	8·49	8·12	7·3	5·38	4·20	3·21	3·16	4·5	5·9	6·11	7·18	8·22

All records of time have been corrected to Greenwich Mean Time.

Finally, the actual mechanical process of grazing was observed and will be discussed in some detail.

Results and Discussion

General.—The complete records describing the monthly activities of Cheviot sheep throughout a full year are shown in Table 3, whilst Table 2 gives the average results for the whole year. It will be seen that

TABLE 2. *Yearly Averages obtained from Monthly Data, 1946–7*

	Grazing	*Resting*	*Idling*
	hr. min.	*hr. min.*	*hr. min.*
07·00–19·00 hours . .	6 52	4 25	0 43
19·00–07·00 hours . .	2 33	8 30	0 57
24-hr. total . . .	9 25	12 55	1 40

out of the 24 hrs. the sheep spent, on an average, a total of 9 hrs. 25 min. in the selection, collection, and consumption of food, 12 hrs. 55 min. resting, and 1 hr. 40 min. in other occupations. Between 07·00 and

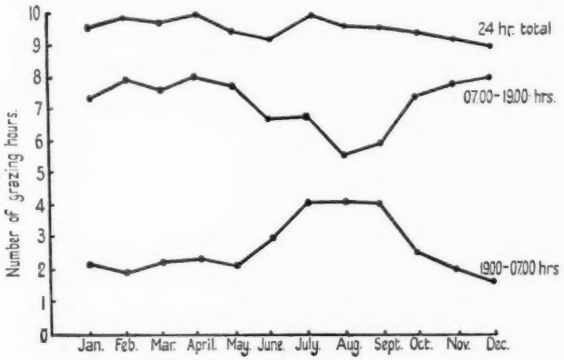

FIG. 1. Seasonal variation in grazing hours.

19·00 hrs., 6 hrs. 52 min. were spent grazing, 4 hrs. 25 min. resting, and 43 min. idling; between 19·00 and 07·00 hrs., 2 hrs. 33 min. were spent grazing, 8 hrs. 30 min. resting, and 57 min. idling.

Grazing.—Table 3 discloses how careful the interpretation of these figures must be, for the variation at different times of the year was very considerable. Fig. 1, for instance, serves to demonstrate graphically how the time spent grazing varied throughout the year. It will be seen that during the summer months considerably less time was spent grazing in the 07·00 to 19·00 hrs. period than between the same hours during the winter months. For the 19·00 to 07·00 hrs. period the opposite was the case. The longer period of daylight and the excessive heat of the day in summer are doubtless the reasons for this.

Of great interest is the approximately constant time devoted to grazing per 24 hrs. throughout the year. Since it is well known that sheep at pasture lose weight and condition during the winter months, it must be assumed either that the efficiency of winter grazing was lower than that of summer grazing, or that, although the sheep consumed similar quantities of food all the year round, the winter herbage with its higher fibre-content and poorer nutritive value provided only a sub-maintenance

diet. It is of course possible, and indeed probable, that both of these factors were involved. In this connexion the work of Smuts and Marais [22] showed that sheep in the Transvaal lost condition in winter because the nutritive value of the food was then lower, and not because they then consumed less weight of food per unit of body-weight.

Resting.—Fig. 2 indicates that the total number of hours devoted to rest during a 24-hr. period remained approximately the same throughout the year, but that, as with grazing, there were very significant variations between certain months in the amount of rest during the 12-hr. periods.

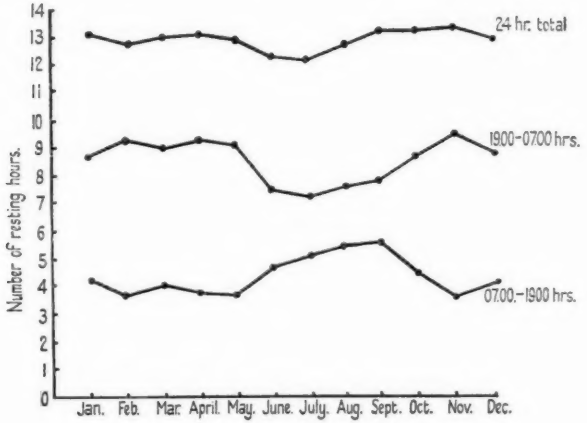

FIG. 2. Seasonal variation in resting hours.

Day-time rest was greatest in summer, whilst night-time rest was greatest in winter. Again, this may be explained in the light of the prolonged period of daylight and the excessive day-time heat of the summer months.

Distances travelled.—Table 4 gives the miles walked by the animals in each 12-hr. and 24-hr. period of each month, and also the averages for the whole year. The average daily distance walked was 2·61 miles, 2·06 m. of this being between 07·00 and 19·00 hrs., and 0·55 m. being between 19·00 and 07·00 hrs. Fig. 3 illustrates more clearly by a graph how the distances varied month by month. It will be seen that most travelling was done in spring and autumn, and least in the summer. It is also of interest to note that the animals walked proportionately more at night in the summer than in the winter.

Periodicity of behaviour.—Not only is the monthly distribution of the various activities of interest, but so also is the daily distribution. Fig. 4 shows how the times of grazing and resting were alternated throughout the 07·00 to 19·00 hrs. periods for the 12 months. The periodicity of behaviour is obvious. The activities of the animals were divided into grazing and miscellaneous activities, and it will be seen that the times

TABLE 3. *Monthly Data through a Full Year (1946–7)*

	1946						1947															
	Oct.		Nov.		Dec.		Jan.		Feb.		Mar.		Apr.		May		June		July		Aug.		Sept.	
	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.
Hrs. 07·00–19·00:																						
Grazing	6	54	7	12	7	20	7	20	7	56	7	30	7	40	7	19	6	21	6	2	5	16	5	38
Resting	4	18	3	44	4	3	4	12	3	40	4	0	3	56	3	54	4	47	5	22	5	27	5	39
Idling	0	48	1	4	0	37	0	28	0	24	0	30	0	24	0	47	0	52	0	36	1	17	0	43
Hrs. 19·00–07·00:																						
Grazing	2	20	1	53	1	30	2	10	1	53	2	12	2	13	1	58	2	53	3	56	3	55	3	44
Resting	8	49	9	28	8	53	8	50	9	10	9	0	9	10	9	2	7	27	7	11	7	20	7	34
Idling	0	51	0	39	1	37	1	0	0	57	0	48	0	37	1	0	1	40	0	53	0	45	0	42
Total 24 hrs.:																						
Grazing	9	14	9	5	8	50	9	30	9	49	9	42	9	53	9	17	9	14	9	58	9	11	9	22
Resting	13	7	13	12	12	56	13	2	12	50	13	0	13	6	12	56	12	14	12	33	12	47	13	13
Idling	1	39	1	43	2	14	1	28	1	21	1	18	1	1	1	47	2	32	1	29	2	2	1	25

TABLE 4. *Distances travelled by Sheep (in miles) (1946–7)*

	1946			1947									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Aver.
Hrs. 07·00–19·00	2·05	2·20	1·65	1·90	1·75	2·00	2·10	2·50	2·45	2·00	1·55	2·50	2·06
Hrs. 19·00–07·00	0·50	0·40	0·46	0·30	0·50	0·43	0·48	0·52	0·85	0·75	0·55	0·65	0·55
Total 24 hrs.	2·55	3·00	2·11	2·20	2·25	2·43	2·58	3·02	3·30	2·75	2·10	3·15	2·61

of grazing were surprisingly regular in every month. Fig. 5, which shows the times sheep grazed between 19·00 and 07·00 hrs., does not exhibit the same obvious periodicity, but it is clear that the grazing was concentrated in the first 6 hrs., and that very little was done between 01·30 and 04·30 hrs.

Idling.—The sheep spent a part of each day in an apparently purposeless manner. The average amount of time thus spent per 24-hr. period was 1 hr. 40 min., 43 min. of which occurred between 07·00 and 19·00 hrs., and 57 min. between 19·00 and 07·00 hrs. Table 3 shows that these figures fluctuated considerably throughout the year. There was no

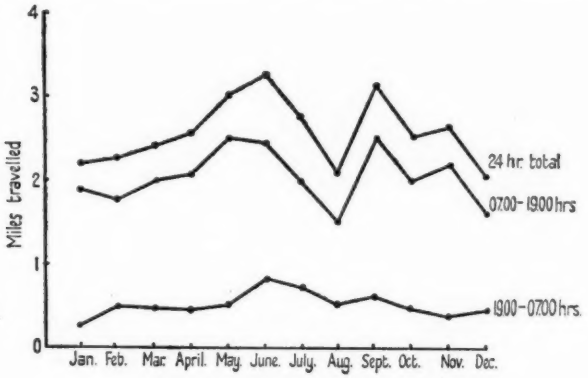

FIG. 3. Seasonal variation in distance travelled.

obvious reason for these variations, and the animals' actions during the period were not at all regular.

Mechanics of grazing.—Johnstone-Wallace and Kennedy [13] have described the mechanical process of grazing in beef cattle, and have indicated that physical factors are perhaps of greater importance in influencing the selection of herbage than has previously been thought. This seems true also of sheep. The work of Stapledon and Milton [6], White [31], Davies [23], and others has shown that sheep exhibit definite preferences not only among plant species, and among the same plant species at different stages of growth, but also among various parts of an individual plant. The reasons determining this selective habit are obscure [24]. H. O. [25] showed that the contents of sugar, protein, and vitamin of plants are apparently not the reasons for their being selected. Woodman and Evans [26] could find no relation between mineral-content and palatability, and Tiemann and Mueller [27] concluded that there was no correlation between palatability and nutritive value of plants. Davies [23] showed that sheep prefer to eat plants in a young stage of growth, and suggested that it was merely coincidence that the young herbage was more nutritious. He indicated that the succulence of a plant is of considerable importance in its selection, and that harshness and hairiness tend to lower palatability. That the animal's response

to the sensory stimuli, smell, taste, sight, and touch is of importance in herbage selection has already been suggested [12, 19, 28, 29]. To what degree these stimuli influence selection is, however, doubtful; Tribe [30] has found that the sense of smell is of only supplementary importance.

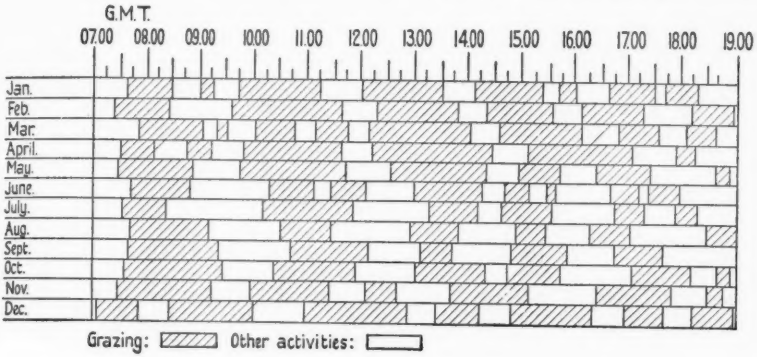

FIG. 4. Times of grazing, 07·00–19·00 hrs.

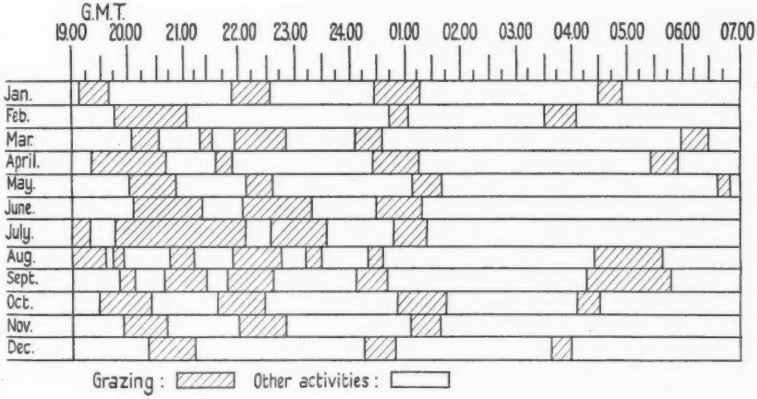

FIG. 5. Times of grazing, 19·00–07·00 hrs.

An intimate study of sheep-grazing shows that the leaves and stems of grasses, legumes, and weeds have to be severed by two jaws, which together work very close to the ground and provide a functional aperture of approximately 1¼ in. diameter. The lower jaw possesses one row of teeth which, in the biting action, presses hard upon a fibrous pad on the upper jaw. In these circumstances it is not surprising that the plants selected by the animal are those most easily gathered by this simple mechanism. This means that small, easily torn plants, and parts of plants, will tend to be preferred by the grazing animal merely for

mechanical reasons. Numerous physiological and psychological factors are always at least potentially concerned, and may, in fact, prove to be limiting factors at any time; nevertheless physical and mechanical factors are probably of great importance.

Summary

1. General features of the grazing behaviour of Cheviot sheep on lowland pasture were studied under suitable but circumscribed conditions over continuous periods of 24 hrs. during 12 consecutive months. The seasonal influences on the times spent grazing, resting, and idling, and the distances travelled were recorded.

2. Under the experimental conditions of this research, it was found that:

(*a*) an average total of 9 hrs. 25 min. per 24 hrs. was spent grazing. This figure remained approximately constant throughout the whole year, although in winter considerably more grazing was done than in summer between 07·00 and 19·00 hrs., and considerably less between 19·00 and 07·00 hrs.

(*b*) An average total of 12 hrs. 55 min. per 24 hrs. was spent resting. Although this figure remained approximately constant throughout the whole year, in summer considerably more resting was done than in winter between 07·00 and 19·00 hrs., and considerably less between 19·00 and 07·00 hrs. An average total of 1 hr. 40 min. per 24 hrs. was spent idling.

3. The sheep walked an average total distance of 2·6 miles per 24 hrs., 2·06 m. being between 07·00 and 19·00 hrs., and 0·55 m. between 19·00 and 07·00 hrs. Most travelling was done in spring and autumn, and least in summer. The animals walked proportionately more at night in the summer than in the winter.

4. There was an evident periodicity of behaviour between 07·00 and 19·00 hrs. when there was an average of 6 periods of grazing. At night the grazing was concentrated between 19·00 and 01·30 hrs., and the same obvious periodicity of behaviour was not apparent.

5. The mechanics of sheep-grazing are discussed, and the importance of mechanical factors in the selection of herbage indicated.

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BREEDING FOR DISEASE-RESISTANCE IN POTATOES

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POTATO varieties are subject to a wide array of diseases and frequently heavy losses in the crop are sustained. The annual toll, particularly of blight and viruses, is considerable and it could doubtless be substantially reduced by the production of new types with greater resistance to a wider range of diseases. In the potato family, both cultivated and wild, a high degree of resistance to practically every disease of importance has been discovered. It is the purpose of the breeder to locate these qualities and to bring them together in suitable new varieties so that losses may be reduced and a higher yield of saleable tubers per acre produced.

Natural resistance to a disease is a complex represented by the aggregate effect of numerous morphological and physiological characteristics of the plant, such as thickness of cuticle, density of pubescence, osmotic concentration of sap, sensitiveness of cells, &c. The protective agencies may differ in different varieties, resulting, by their combined effect, in the appearance of many different degrees of resistance. In such circumstances, a number of genetic factors inherited in quantitative fashion must bear upon the natural resistance of a variety and determine its ultimate reaction. The analysis of these factors is difficult and the problem of accumulating them by breeding methods to increase resistance may take a long time to solve. If, however, one particular character should predominate in its contribution towards resistance, it may be possible to study that character as a separate unit and to devise a breeding programme for its utilization.

The various characters which contribute towards resistance may be divided into two main groups: (1) those which determine the resistance of the plant to infection, i.e. infection degree, and (2) those which determine the reaction of the plant after infection has occurred, i.e. tolerance degree. The combination of infection degree and tolerance degree therefore provide a measure of the plant's resistance. A variety with high infection degree and high tolerance degree accepts the pathogen readily and offers little opposition to its presence. If it forms a symbiotic relationship with the invader, as in the case of certain viruses, it is a carrier. On the other hand, a variety with low infection degree and low tolerance degree will seldom become infected, but if infection should occur the plant will react vigorously and may even destroy the invading organisms. The numerous combinations of different infection degrees and tolerance degrees determine the range of resistance and susceptibility to diseases found in potatoes.

Obviously, the most valuable condition is low infection degree which, in extreme cases, constitutes true immunity. Unfortunately true immunity is a comparatively rare character in the potato family, and as an aim in practical breeding it has given few encouraging results. A low infection degree which falls short of immunity is more readily attainable

and any scheme for breeding disease-resistant plants should include, at least, this objective as an integral part. If, however, low infection degree can be combined with low tolerance degree whereby the plant responds to infection with necrosis and localizes the invading organism, then resistance will be greatly enhanced. Varieties of this type are known as hypersensitive or field immune, and the protection afforded by their necrotic response is, for practical purposes, equivalent to true immunity. A hypersensitive condition in respect of several parasitic organisms is to be found among potato varieties and it is responsible for the prevention of considerable losses in commercial crops. Moreover, the character is readily distinguishable from other forms of resistance, and in all the cases so far studied it is inherited in Mendelian fashion. It is not surprising, therefore, that much of the breeding work dealing with disease-resistance properties is concerned largely with tolerance degree and the production of hypersensitive varieties.

Resistance phenomena in plants, however, constitute only part of the intricate problem of host-parasite relationships. If all parasitic organisms were constitutionally unalterable, the breeding of resistant varieties of crop plants would be quickly accomplished, but nature has provided the lower, as well as the higher, organisms with evolutionary powers to assist in their survival. The production of resistant plants therefore is frequently followed by the appearance of new biotypes of the parasite capable of attacking varieties which were not previously affected. These specialized strains may arise by hybridization or by mutation. In some organisms it is probable that they are constantly being produced, but their presence may not be detected until the appropriate plant-genotypes have been bred to isolate them. With continued development of new strains, the breeding of varieties completely resistant to all possible biotypes may be difficult or even impossible to achieve. In any event, a period of time usually elapses between the introduction of resistant varieties and the appearance of new strains of the disease capable of attacking them. The duration of that time cannot be predicted; it may be only a year or two as in the case of certain strains of blight, or it may be more than 40 years as exemplified by the freedom from wart disease which several old varieties introduced at the beginning of the century have exhibited. The practical value of any new disease-resistant properties introduced may be determined largely by this time-factor.

Wart Disease

The breeding of potatoes resistant to wart disease (*Synchytrium endobioticum*) has been attended with outstanding success. It has frequently been stated that the problem no longer exists since varieties 'immune' to wart are numerous and their numbers are steadily increasing. Certainly, in most countries no new biotype of the fungus has been observed and those varieties originally classified as 'immune' have remained free from the disease. But two new strains of *S. endobioticum*, capable of attacking many of the so-called immune varieties, have been found in Germany [1]. The distribution of these strains is limited and may remain so, but the fact of their existence is an indication that freedom

from wart disease is not necessarily a permanent characteristic of 'immune' varieties.

Freedom from wart disease in many varieties appears to be attributed mainly to the intolerance of the plant's cells to the presence of the fungus, i.e. hypersensitiveness. In such cases the fungus invades the outer cells but quickly succumbs in the necrotic tissue which is produced. Other varieties appear capable of resisting the disease without the formation of necrotic lesions [2] and may therefore be completely resistant to infection, i.e. true immunes.

Resistance to wart disease is a heritable character but the mode of its inheritance is complex and several genes appear to be involved [3, 4]. If, however, hypersensitiveness and true immunity are independently effective in preventing disease, and are controlled by different genes, then a relatively complex system of inheritance would result. But these considerations present no serious obstacle to the production of 'immune' varieties for practical purposes because resistance is inherited as a dominant character and the choice of parental material is wide.

Blight

The problem of resistance to the blight fungus (*Phytophthora infestans*) presents many difficulties since none of the established commercial varieties is immune from the disease or even possesses a satisfactory degree of resistance. The breeder must, therefore, turn to wild unproductive species in order to obtain the genes necessary to combat this disease. The most promising species appears to be *Solanum demissum*, a wild hexaploid form with many non-commercial characteristics. This species has been widely employed in breeding experiments during the last two decades. It comprises a number of varieties, some of which are blight susceptible but others are completely resistant to all known strains of the disease. Resistance is a heritable character which behaves in dominant fashion [5], but the resistant seedlings obtained from the initial crosses contain so many undesirable characters of the wild species that repeated back-crossing to economic varieties is necessary to eliminate them. It is significant that some 30 years have elapsed since the heritable nature of blight resistance in *S. demissum* was first appreciated, yet no completely resistant variety has so far been introduced into commerce.

The type of resistance which predominates in *S. demissum* is the hypersensitive, i.e. the plant is resistant by virtue of its low tolerance degree. Müller [6] found that resistance genes function only as accelerators of the defence reaction of which both susceptible and resistant genotypes are capable, i.e. they control only the sensitiveness of the cells to the presence of the fungus. Hypersensitive plants, when attacked, react quickly and necrotic spots appear at the points of entry of the fungus. The necrotic tissue prevents the further penetration of the parasite and no appreciable damage is caused to the plant.

Progress in the breeding of such hypersensitive varieties has been greatly retarded by the appearance of new and more virulent strains of the fungus. Originally only one strain was known in Britain, but when promising seedlings resistant to it were being multiplied, a second strain

B, which was able to attack them, appeared. In order to obtain plants resistant to this new strain, and also to the original or A strain, selections were made in the earlier generations of seedlings bred from *S. demissum*. These plants were less highly developed in respect of essential commercial characters and their enforced adoption as parents represented a setback of several years. Promising seedlings, resistant to both the A and B strains, were eventually bred, however, but again the work was checked by the appearance of a third strain C, to which this material was susceptible. Again the earlier generations were tested and plants which successfully resisted all three strains were selected. The improvement of the ABC-resistant types has been in progress for several years and they have proved resistant also to 10 strains of German origin. But this material does not represent the culmination of the series of reverses caused by parasitic specialization, for a further new strain has been found in Tanganyika which can destroy several groups of the ABC-resisters. The remaining groups, however, continue unaffected by it, and being relatively free from the wild characters of *S. demissum*, they have better prospects of reaching commercial standard unscathed than have any of their predecessors.

The number of strains of blight which may ultimately be found will, no doubt, be very large and their identification will depend upon the range of genotypes available to isolate them. The comparatively small number of major genes contained in *S. demissum* may appear inadequate to differentiate so many biotypes of the fungus, but the evidence suggests that each major gene controls resistance to a group of strains, the individuals of which require the presence or absence of minor genes in the host plants for their identification.

The experimental evidence indicates that, in so far as the three biotypes A, B, and C are concerned, resistance is controlled primarily by four major dominant genes designated Ra, Rb, Rc, and Rbc which confer effective resistance to strains A, A+B, A+C, and A+B+C respectively [7]. In these circumstances any plant which is resistant to either B or C is also resistant to A, suggesting that quantitative differences may exist. But since one variety may be resistant to B and susceptible to C whilst another may be resistant to C and susceptible to B, it is apparent that qualitative differences in resistance are also present.

The outstanding problem in overcoming the blight fungus is the attainment of maximum resistance in the final stages of the breeding operations. With repeated back-crossing to susceptible commercial varieties, the resistance genes must be expected to disperse, but by the subsequent intercrossing of different resistant breeding-lines it may be possible to reassemble them to the required concentration. This may be illustrated by the effect of crossing a plant carrying the gene Rb with one carrying the gene Rc. The resulting progeny, on testing with strains B and C independently, segregated in the ratio of 1 RbRc:1 Rbrc:1 rbRc:1 rbrc, approximately. Thus about 25 per cent. of the offspring were resistant to both strains of the disease. On that evidence it is apparent that production of high-yielding seedlings from *S. demissum* by means of repeated back-crossing to commercial varieties represents

only part of the breeding work. The remainder consists of reassembling the scattered resistance genes by means of intercrossing the appropriate resistant lines. If recombination can be adequately achieved it seems probable that an effective resistance to all strains of blight may be accomplished.

Mosaic

The mosaic diseases found in potato crops are caused by one or more of a number of viruses and virus strains. Since varieties may respond differently to infection with a single virus as well as to infection with different viruses, the range of symptom-expressions occurring in the field is wide and complex. In practice, however, the visible symptoms of the diseases are described as mild or severe according to their intensity. Of the list of viruses which can cause mosaic, three of them, viz. A, X, and Y, are particularly important since they are responsible for nearly all the mosaic diseases occurring in commercial crops. Viruses A and Y are transmitted by greenflies (Aphides) and are spread under field conditions mainly by these insects, whilst virus X appears to be spread almost entirely by contact. Each of these viruses may individually cause a mild mosaic, but in some varieties X and Y are capable of producing symptoms of severe mosaic. Combinations of viruses usually produce a severe form of mosaic.

Resistance to a virus is determined by a number of factors which contribute towards either the infection degree or the tolerance degree of the plant. An ultimate low infection degree, or true immunity, has been observed in an American seedling U.S.D.A. 41956 in relation to virus X [8]. Repeated attempts to infect it with virus X have failed and in breeding experiments the character was found by Stevenson *et al.* [9] to depend on the presence of two complementary genes. True immunity of this type apparently occurs very rarely and has not been observed in any commercial variety. A less extreme degree of resistance to infection is frequently found, however, and varieties so constituted are able to reduce the speed of infiltration of the virus through the crop and so remain productive for a relatively long period.

Much of the experimental breeding work for resistance to the mosaic viruses has been concerned with tolerance. Cockerham [10] discovered that certain varieties are immune from viruses A and X under field conditions as a result of the extreme susceptibility of their tissue. This hypersensitive condition proved to be inherited in simple dominant fashion [11], and since it was already present in a number of commercial varieties, e.g. Epicure and King Edward VII, a convenient method of controlling viruses A and X by breeding methods was at hand. The value of this hypersensitiveness is emphasized by the fact that Epicure and King Edward VII have remained substantially free from the troubles associated with these viruses throughout their long life of approximately 50 years.

Breeding experiments have shown that hypersensitiveness to most of the strains of virus X is controlled by a single dominant gene Nx, and that hypersensitiveness to virus A is similarly determined by a gene Na

which is closely linked to Nx. As a result of this linkage the problem of virus A is usually solved by breeding varieties hypersensitive to virus X.

Resistance to virus Y has been more difficult to achieve. The virus is widespread and often severe in its effect, and no European variety has proved hypersensitive to it. Some varieties, when infected with virus Y, may exhibit necrotic symptoms in the early stages, but later a non-lethal streak develops and eventually a mosaic. If a variety is tolerant to the virus, e.g. Herald, the crop may not be greatly reduced but it acts as a source of infection for other less tolerant varieties which may be severely affected. A more satisfactory type is that which is relatively resistant to infection, e.g. Champion, but the degree of protection so far obtained by this means is inadequate.

Several wild species of potato, e.g. *S. simplicifolium* and certain varieties of *S. demissum*, react with necrosis to infection with virus Y [12]. The necrotic response, controlled by a gene Ny, is, however, variable in its intensity, ranging from tiny lesions typical of hypersensitiveness to complete necrotic collapse. The gene Ny appears to be less self-sufficient than Na or Nx, and its effect is influenced to a greater extent by other factors, such as age of the plant and intensity of infection. The evidence suggests that hypersensitiveness is reached only in the presence of other genetic factors which enable the host-plant to localize the virus at the site of infection [13].

A necrotic response to infection with virus Y under certain conditions has also been observed in the U.S.A. in the variety Katahdin [14], and in Australia in the variety Snowflake. The potentialities of these two varieties have been investigated by Hutton [15, 16], who found that hypersensitive seedlings could be bred from them, although the proportions in which they appeared were relatively small. Some of the seedlings were inconsistent in their reactions, giving lethal or localized necrotic responses according to the stage of growth and vigour of the plant at time of inoculation. In view of the segregations obtained, it is probable that the gene complex in this material differs from that controlling virus Y reactions in *S. simplicifolium* and *S. demissum*. In both cases, however, field immunity from virus Y is attainable provided the necrotic response is supported by the necessary additional factors.

Leaf-roll

No form of immunity from leaf-roll has yet been found in potatoes, either among the cultivated varieties or wild species, but certain varieties such as Shamrock and Southesk possess a high degree of natural resistance to the virus. In addition, a number of foreign varieties, particularly German, of comparatively recent origin are claimed to be relatively resistant to the disease. Presumably the resistance which these varieties exhibit is due to a low infection degree since typical leaf-roll symptoms result when successful infections occur. Breeding experiments with these varieties show that the resistance present in the parent plants is reflected in their progenies in the manner of quantitative inheritance. The intercrossing of resistants gives a high proportion of resistant offspring whilst the seedlings of susceptible plants are largely susceptible.

By means of close inbreeding highly resistant seedlings have been produced and it appears possible to intensify resistance even to the extent of entirely preventing infection.

Although hypersensitiveness to leaf-roll has not yet been recorded, varieties exhibit wide differences in degree of tolerance to the virus. The more tolerant types make good growth in association with the virus and show little reduction in size at maturity, but the less tolerant varieties are severely dwarfed by comparison. No doubt a low tolerance degree would be an added advantage if combined with low infection degree, as the few plants which acquired the disease would be so severely reduced in size that the virus would tend to be self-eliminating.

Unfortunately no convenient laboratory method of assessing resistance has yet been developed and the ordinary method of field-testing is too protracted for rapid progress in the concentration of resistance genes.

Scab

The breeding of varieties resistant to common scab (*Actinomyces scabies*) has been in progress for many years, particularly in Germany and the U.S.A., and some highly resistant forms have been produced. Recent breeding work has been based largely upon the German varieties, Arnica, Hindenburg, and Jubel, which rank high in the list of scab-resistant commercial types. Absolute immunity from scab has not been found among commercial sorts, but the degree of resistance exhibited by the above-named varieties is sufficiently high to provide a valuable means of restricting the amount of damage caused to crops. It is probable that resistance may be increased still further by intercrossing within the group of resistant varieties. Although different strains of the fungus are known to exist [17], there is little evidence of specialization becoming a major problem.

In a study of the inheritance of resistance to common scab, Krantz and Eide [18], assuming the type of inheritance to be autotetrasomic, found that the reaction was controlled principally by the influence of one gene. The five possible genotypes corresponded to five different breeding groups observed in a collection of varieties and seedlings.

Immunity has been claimed by Reddick [19] in respect of several wild species, e.g. *S. commersonii*, *S. chacoense*, and *S. Jamesii*, but unfortunately these species are difficult to cross and the prospects of breeding their immunity into economic varieties are not encouraging.

Breeding Methods

The technique of seed production in potatoes is relatively simple where full fertility prevails, but the incidence of sterility and incompatibility among the members of the potato family presents a severe handicap in practically every breeding programme. These difficulties are in part counterbalanced by the fact that potatoes are normally propagated vegetatively, making possible the multiplication of selected segregates without affecting their genetic constitution. Further, heterozygosity is the rule rather than the exception in potato varieties and the range of segregations and recombinations obtained is consequently very wide.

The procedure followed in practical breeding operations is determined by the nature of the characters desired and the type of plants in which they are found. Genes controlling resistance to the more important diseases are known to exist but they are scattered throughout the potato family. Some are found in cultivated varieties and are readily available, but others of great potential value to agriculture exist only in the indigenous potatoes of America [20]. It is necessary, not only to bring these resistance qualities together, but to include also the numerous commercial features which constitute an economic variety. If wild species are employed in hybridization the introduction of undesirable characters is unavoidable and it is necessary to breed and select through several generations in order to eliminate them. This involves backcrossing with economic varieties and the selection in each generation of the best resistant segregates for use as parents. The number of backcross generations necessary to eliminate all the undesirable characters of the wild species may vary but it is seldom less than three.

Apart from experimental material of recent origin, effective resistance to the blight fungus is found only in wild species and the most promising of these, *S. demissum*, forms the basis of most of the present-day breeding programmes. The crossing of *S. demissum* (hexaploid) with commercial varieties (tetraploid) gives hybrids with unbalanced chromosome complements and introduces sterility problems which limit the scope of the breeding work in subsequent generations. These difficulties, however, may largely be avoided by first crossing *S. demissum* with a diploid species to synthesize a resistant tetraploid form. This hybrid may then be crossed with commercial varieties to obtain triple hybrids that combine fertility with the necessary resistance to blight.

In the course of breeding out the 'wild' characters by repeated backcrossing, it is possible to introduce some resistance qualities found in cultivated varieties, e.g. resistance to leaf-roll, field immunity from viruses A, X, and Y, resistance to scab, and resistance to storage diseases. If such genes can be accumulated in the early stages, the prospects of obtaining economic results within a reasonable time will be increased greatly.

The time required for the fulfilment of a comprehensive breeding programme can hardly be estimated. It will depend to a large extent upon the mutability of the various parasitic organisms and the ability of the mutants to persist under natural conditions. But the accumulation of resistance genes as such may be accomplished in a relatively short time. For example, in four generations of breeding from *S. demissum* a variety has been produced which combines good cropping capacity and good cooking quality with 'immunity' from wart disease, effective resistance to blight strains A, B, and C, field-immunity from several strains of viruses A, X, and Y, and a high degree of resistance to leaf-roll, scab, and storage diseases. These qualities alone will not necessarily ensure the success of a variety under general cultivation, for there are many other factors to be considered, but the variety quoted serves to illustrate that breeding for disease-resistance in potatoes, although possibly a long-term problem, is a practical proposition of great potential value.

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THE MOVEMENT OF TWO BREEDS OF PEDIGREE DAIRY CATTLE IN GREAT BRITAIN

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THERE is a considerable regional variation in the annual milk yield per cow in the various parts of Great Britain. Very roughly, the centre of high yield and low butter-fat percentage is in the south-east, with a decrease in yield and an increase in fat percentage westwards and to a smaller extent northwards. This point was raised by Edwards [1], when he pointed out that the milk yield in Lancashire for Friesians and Shorthorns was only 75 per cent. of the yield of the same breed in Essex. The general picture for the whole of England and Wales is given in Fig. 1, which shows the average 305-day yield and fat percentage for Friesians and Shorthorns in the different Milk Marketing Board Regions. These figures, of course, refer to all animals of the breed type in the region. In addition, there is given the percentage of all milk-selling cows which are recorded in that region.

Edwards also suggested that the difference in yields might be related to the general level of the dairy industry in the two counties concerned. The density of cattle is very much higher in Lancashire and there is also a smaller supply of home-grown foodstuffs, such as beans and sugar-beet tops, than in Essex. In addition, it is probable that Lancashire farmers deliberately rely more on grass and hay, whereas on the east coast pasture conditions are not so good and more expensive foodstuffs must be fed. This paper is an attempt to discover to what extent any regional adaptation could be possible within the breeds. If the amount of movement of breeding stock is small, then there is a high probability that selection under the different climatic and feeding conditions could set up local genetic isolation. However, the results show that the flux of genes is so great as to even out, with few exceptions, any regional genetic differences there may be and to render very unlikely the formation of any new adapted sub-breeds.

It has been suggested that some of the regional variation may be due to differences in the level of recording. As willingness to record is presumably connected with good management, it would be expected that within *any given region* the higher the percentage of herds recorded the lower the average yield. If the percentage recorded is low, only the cream of the herds will be measured, and as more herds are recorded, the general level of those recorded will drop. However, reference to Fig. 1 shows that the low yielding regions are also those with a low percentage recorded. This can only mean that the true average yield will show a greater variation than is apparent from the above figures.

Measurement of migration.—For each breed, about ten districts of the country were chosen, generally of the size of one or two counties. They were chosen as far as possible to have roughly the same total pedigree population of the breed under consideration. Owing to the different

geographical distribution of the two breeds, slightly different counties had to be chosen in the two cases. Then the last available herd-books were taken (1943 for Friesian and 1945 for Shorthorn) and a list made

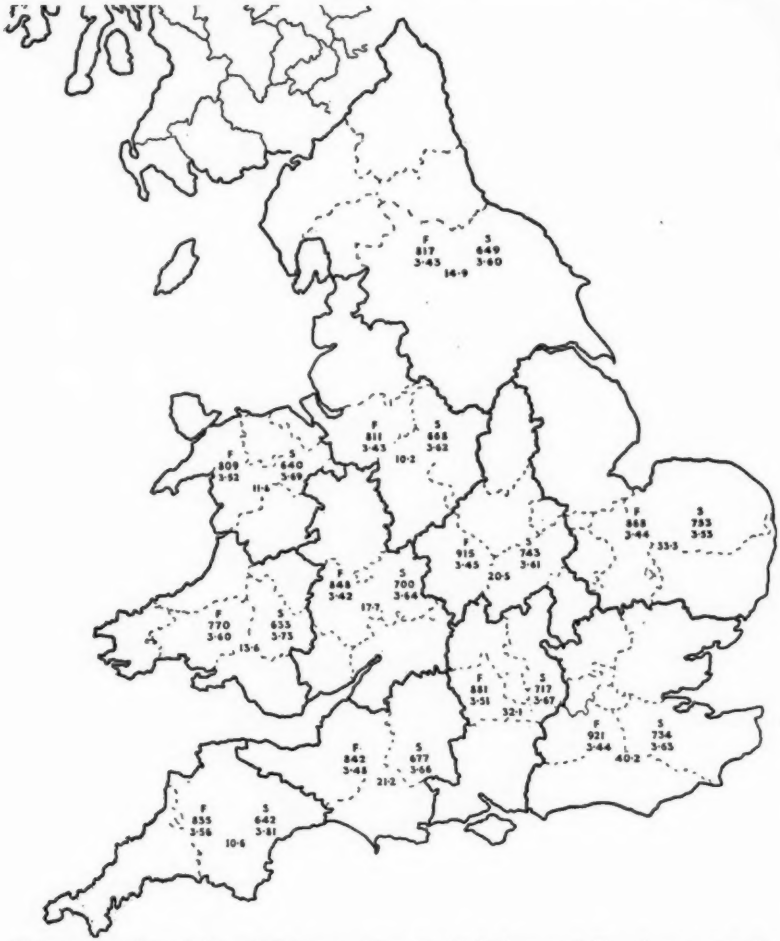

FIG. 1. 305-day yield and fat percentage for Friesians and Shorthorns and the percentage of all milk-selling cows recorded, for the Milk Marketing Board regions.

of the female entries in each 'county'. Then 100 females were taken at random from each 'county' and their pedigrees traced back for two generations. The county of birth of the various ancestors was then noted. (The male entries were excluded since the breeder's decision to enter would, in that case, be more likely to depend on the pedigree of the animal.)

For the purpose of classifying the origin of the ancestors, England and Wales were divided into eight areas, as shown in Fig. 2. In addition, ancestors were found coming from Holland, Ireland, and Scotland. The

FIG. 2. Classification areas for place of birth of ancestors.

only main difference in the method used in the two breeds was that sample counties were taken from Scotland for Friesians and not for Shorthorns, as it was considered that the majority of Scottish Shorthorns would be of the beef type.

Results

If 22 of the animals born in Cumberland had sires born outside the county, then we will say that the 'replacement index' for sires is 22 per

cent. If we average the indices for sire and dam we get the genetic replacement, that is, the fraction of genes brought in from outside during one generation. The results for the two breeds are given in Tables 1 and 2.

TABLE 1. *'County' Replacement in the Shorthorn Breed*

County	*Sire*	*Dam*	*P.g.S.*	*P.g.D.*	*M.g.S.*	*M.g.D.*
Cumberland	22	4	30	18	13	9
Northumberland and Durham	63	20	84	73	64	33
Lancashire	9	13	24	24	23	14
Shropshire and Herefordshire	78	30	95	84	81	51
Norfolk and Suffolk	50	18	82	57	77	32
Warwick	70	26	79	78	67	39
Carmarthen	50	9	66	59	53	18
Somerset	49	21	60	47	54	34
Wiltshire and Hampshire	64	18	79	65	56	32
Kent	48	21	54	62	57	29
Average	50·3	18·0	65·3	56·7	54·5	29·1

TABLE 2. *'County' Replacement in the Friesian Breed*

County	*Sire*	*Dam*	*P.g.S.*	*P.g.D.*	*M.g.S.*	*M.g.D.*
Aberdeen, Fife, and Kincardine	64	24	82	63	63	37
Ayr and Renfrew	54	19	69	60	64	26
All Scotland	20	0	50	21	21	3
Cumberland	62	54	94	72	80	60
Northumberland and Durham	54	25	87	65	49	42
Lancashire	59	19	83	59	59	38
Shropshire and Herefordshire	73	33	88	88	80	46
Norfolk and Suffolk	71	21	89	75	66	29
Warwickshire and Leicestershire	54	31	81	72	65	55
Carmarthen	71	43	93	90	81	54
Somerset	54	21	82	64	51	39
Wiltshire and Hampshire	57	32	71	66	48	35
Essex	34	10	52	42	34	21
Average	55·3	28·9	79·0	64·9	57·6	38·3

Note to Tables: P.g.S. = Paternal Grand Sire, &c.

In addition, the number of animals whose sires were born in the same herd as themselves was determined. It was 17 per cent. for the Shorthorns and 21 per cent. for the Friesians.

In considering the detailed origin of the ancestors, we can proceed slightly differently. We can find the total contribution of sires by an area to the total number of sires in the sample, but that would bias in the case of those areas containing two sample counties. This can be avoided by

considering only half the animals from those areas with two counties. We can thus find the relative contributions of the different areas to the total sample. The results are given in Tables 3 and 4.

TABLE 3. *Shorthorns*

Contribution of the Areas to the Total Sample (800)

Area	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Ancestor:										
Sire	202	53	57	74	69	87	109	113	33	1
Dam	134	89	93	87	88	94	106	100	7	0
Total parental	168	71	77	80	78	91	107	106	20	1
P.g.S.	229	31	30	92	54	93	107	125	30	6
P.g.D.	217	44	48	67	64	84	126	95	27	4
M.g.S.	216	61	45	82	51	95	125	91	24	10
M.g.D.	165	81	80	79	79	85	115	101	12	4
Total grandparental	207	54	51	80	62	89	118	103	23	6

TABLE 4. *Friesians*

Contribution of the Areas to the Total Sample (900)

Area	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*11*
Ancestor:										
Sire	97	110	48	96	50	69	59	183	173	15
Dam	105	84	68	87	93	107	84	118	149	7
Total parental	101	97	58	91	71	88	71	150	161	11
P.g.S.	49	63	24	53	30	28	36	246	108	263
P.g.D.	79	79	45	89	52	83	90	146	178	58
M.g.S.	85	95	37	75	54	67	63	185	193	54
M.g.D.	89	68	69	71	89	96	102	126	179	12
Total grandparental	79	76	44	72	56	68	73	176	160	97

Figures above 100 for areas from which samples were taken (1–8 in Shorthorns, 1–9 in Friesians) show that these areas are contributing more than would be expected. In fact, there is a regular flow of genes from the sample areas whose contributions are more than 100 to those whose contributions are below 100.

Discussion

The figures reveal a very considerable amount of migration from area to area. As might be expected, the migration is larger among bulls than cows, between two-thirds and three-quarters of the total migration being due to the former. The overall figures for the breeds would seem to show more movement of breeding stock in Friesians than in Shorthorns, more particularly amongst the cows. The general level of migration is very high with the exception of areas like Cumberland and Lancashire for Shorthorns, and Essex and Scotland for the Friesians. In Shorthorns, for instance, the lowest genetic replacement per generation (with the exception of the above two counties) is 35 per cent. This would mean

that in 4 generations (16–20 years) at least 87 per cent. of the genes in an area will be of outside origin. It is difficult to believe that any local differentiation could persist against this migration pressure, or that any selection pressure could be sufficiently large as to set up new differentiation. This is not to deny any herd differences within the districts but to show that, in the main, the districts themselves are not likely to form genetically distinct units. As far as concerns the sources of genes and breeding stock, as might be expected, those areas with low replacement indices themselves are the ones which contribute most to the rest of the country. Thus, in the Shorthorns, the north-west contributes 16 per cent. of the bulls used elsewhere and 25 per cent. of the bulls used in the whole country. The only two other areas which are sources of genes are the central southern and south-eastern areas. Most of the bulls from the north-west actually come from Cumberland and Westmorland which, oddly enough, have one of the lowest average yields of any part of England and Wales. The breeders there are, of course, well known for their dual-purpose type of animal.

In the Friesians the two main sources in the parental generation are Essex and Scotland, with the northern areas of England just holding their own. Scotland has a greater influence than Essex, the influence of the former being mainly due to the Douneside and Dennistoun herds, and of the latter mainly to the Rayleigh herds. In the grandparental contribution there is a very large part played by sires imported from Holland. These would have for the most part been from the 1936 importation, which consisted of 47 bulls and 48 cows. In fact, in 1943 these animals had contributed over 10 per cent. of the total genes in the breed. The use of the sons of these bulls has caused an under-representation of home-bred bulls amongst the paternal grandsires. This seems in particular to have affected the bulls drawn from Scotland, since the grandsire contribution is less than would be expected from that of the sires.

In general, the results suggest that there is very little genetic isolation within these pedigree breeds, with the possible exception of the north-west of England for Shorthorns. Here, however, the isolation is only in the sense that there are few replacements. However, in fact, the influence of the area on the breed is fairly high so that, to some extent, the other parts of the country must be becoming genetically similar to the north-west, because they are continually using bulls from that area. The case of the Friesian breed is somewhat different from that of the Shorthorn, since this is a breed which is still expanding. Here, instead of genetic differences existing and being slowly evened out, any local differentiation would have to build itself up against the great levelling effect of migration.

It may be argued that the figures of the Milk Marketing Board [2] refer to pedigree and non-pedigree cattle and that the above approach applies only to the former. The latter will actually be sired mostly by local bulls themselves drawn from the pedigree herds, so that the levelling process is somewhat slower. However, the fact that the same pattern of regional variation in yield is also shown by the Channel Island breeds, in which pedigree cattle are the rule, is additional evidence to suggest that the regional differences are mainly environmental. If,

in fact, the gradient in yield and butter-fat is assumed to be due to environment and not breeding, any systems of genetic evaluation on absolute yield would tend to penalize unduly those breeders on the west coast. However, the fact that the north-west of England, with a very low yield, contributes so many sires, suggests that this cannot play a very large role in Shorthorns.

From the long-term view of breed improvement, the tendency of the breeds as a whole to operate as breeding units is probably not advantageous. Wright [3] has suggested that probably the best type of breed structure is one in which the breed is split into several semi-isolated sub-groups, which cuts down the chance of the loss of rare genes, possibly advantageous in the future, by chance fixation. In addition, it allows of much greater adaptation to local conditions.

The results here presented have suggested strongly that there is at the present moment little local differentiation in these two breeds. It is proposed shortly to attack the problem in a more direct manner by considering the actual milk yields of daughters of, say, Cumberland bulls used in different counties, and so on. This will enable a direct check on the relative genetic levels in the different areas to be made.

Summary

An investigation has been made by a sampling method of the magnitude of the migration of breeding animals in Friesians and Shorthorns. The movement is of such a magnitude as to preclude the possibility of the existence of much local genetic differentiation, except for the north-west of England in Shorthorns, and Scotland and the region around Essex for Friesians. Apart from these areas, approximately 35–40 per cent. of the genes in any area of county size are replaced in each generation.

Approximately 20 per cent. of the females in these breeds are sired by animals born in the same herd as themselves.

The north-west of England is the main centre of movement of Shorthorns, with the southern counties also contributing a fair proportion. Essex and Scotland are the main contributing centres for Friesians, although Holland contributes a high proportion of the grandparents. Approximately 10 per cent. of the genes carried by animals born in the Friesian breed in 1943 come from the 1936 importation.

This finding suggests that the greater part of the geographical variation of milk yield and butter-fat in England and Wales is due to differences in climate, soil, feeding, and management.

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